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FERTILITY STUDIES ON SOIL TYPES

I. SOME OBSERVATIONS ON CARLETON COUNTY INVESTIGATIONS[1]

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In the past, field experiments of long-time duration conducted by the Experimental Farms Service and other institutions have given valuable information of wide application on the use of rotations, manure and commercial fertilizers in the maintenance of fertility. However, soils vary according to a combination of soil-forming factors as revealed by surveys, and information obtained on any one experimental site may not apply under different conditions. In addition to variations between types, soils also vary within types as a result of farm management. With this thought in mind, simple tests in co-operation with farmers on different soil types have been initiated throughout Canada. The discussion being presented herewith will be illustrated by reference to work being conducted in the vicinity of Ottawa, Carleton County, Ontario.

The soils of the County of Carleton in the Province of Ontario were surveyed during the summer and fall months of 1940 and the results were published as *Report No. 7* of the Ontario Soil Survey in March, 1944 (2). Since the survey was made, certain lines of investigation have been carried out in connection with some of the major soil types with a view to studying their relative present and potential fertility levels as well as the adaptation of different field crops for growth on these soils. This work has been conducted by the Division of Field Husbandry, Experimental Farms Service, in collaboration with the Division of Chemistry, Science Service. A paper containing some of the preliminary results was published in 1945 (1).

The objects of the investigations in Carleton County include the following:

(1) To obtain information on the levels of nitrogen, phosphorus, and potassium in these soils as measured by the response of different crops to these elements applied as fertilizers in field and greenhouse tests.

(2) To ascertain the best ratios of elements in fertilizer formulae, and the most desirable rates of application, for different crops on different soils in field tests.

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TABLE 1.—ESTIMATED YIELDS OF OATS AND HAY ON A NUMBER OF CARLETON COUNTY SOILS

Soil	Oat crop 1941-1947*		Hay crop 1941-1947	
	Number of fields	Bushels per acre	Number of fields	Tons per acre
Uplands sand	5	25	10	0.8
Rubicon sand	35	29	58	1.3
Kars gravelly sandy loam	61	35	51	1.3
Grenville loam	59	36	67	1.5
Manotick sandy loam	82	40	95	1 7
Castor silt loam	56	40	69	1.6
Osgoode loam	50	44	77	1 6
North Gower clay loam	71	43	91	1.8
Carp clay loam	105	47	122	2.0
Rideau clay	100	39	109	1.7

* No estimates for oat crop in 1944.

(3) To correlate chemical tests for phosphorus and potassium with crop response to these elements applied in greenhouse and field experiments.

(4) To obtain other chemical data, useful in evaluating the properties of the different soils.

The soil types on which work has been done in Carleton County may be described briefly as follows: (1) Uplands sand, an excessively drained acid sand; (2) Rubicon sand, an acid soil developed on an undulating plain, usually with rather imperfect drainage; (3) Kars gravelly loam, a light, excessively drained soil usually developed on gravelly ridges; (4) Manotick sandy loam, developed on an undulating plain of acid clay which has been covered by layers of fine sand and silt of varying depth, with the result that the cultivated layer may be rather variable in composition; (5) Castor silt loam, an imperfectly drained soil of intermediate texture; (6) Grenville loam, a well-drained morainic soil; (7) Osgoode loam, imperfectly drained and frequently occupying poorly drained basins between ridges of till; (8) Carp clay loam, a gently undulating soil with moderate to slow drainage; (9) North Gower clay loam, a poorly drained soil; and (10) Rideau clay, a very heavy, moderately drained, soil.

For the past few years estimates of the yields of oats and hay on a number of fields on the above soil types have been obtained. Tours were made through the more extensive areas of soil types, and estimates of the yields on the fields along the route were based on the observation of the agronomist. For the present purpose, only average yields for the period will be presented, although the relative rating of the different soils in any year varied with seasonal conditions. The average yields on each of a number of soil types are given for oats and hay in Table 1. These data, although based on a limited number of estimates, show the variation between the soil types in respect to the production of oats and hay crops, and emphasize the value of the survey in providing an inventory of soil conditions. The relative ratings of these soils as contained in the Soil Survey Report (2), are in good agreement with the data in Table 1.

GENERAL TECHNIQUE AND INTERPRETATION OF FIELD, GREENHOUSE AND LABORATORY TESTS

Field Experiments

Field tests with fertilizers for grain and hay crops have been located in co-operation with farmers on a few of the more important soil types. The land is prepared for seeding by the farmer. Application of fertilizers is made at the time of seeding, using a grain drill with fertilizer attachment. Each plot consists of two drill widths (15 feet), and is located at right-angles to the direction of plowing so as to eliminate the variation between plots, resulting from crowns and dead furrows, an appreciable source of error in the case of many imperfectly drained soils with level topography. The lengths of these plots may vary from farm to farm but approximate 200 feet. The yields of each crop are obtained by sampling of the plots. Samples are taken at random except on the plots of grain seeded to hay where crowns and dead furrows cross the plots, in which case the sampling points in the different plots within a block are in a straight line at right-angles to the length of the plots. This technique employed for grain and hay crops on these soils is satisfactory, particularly when the treatments are replicated two or three times.

Different farms on the same soil type may vary considerably in fertility because of differences in farm management. In 1945 on a Castor silt loam, the check plots on one farm gave a yield of 10.7 bushels of oats per acre; but on another farm on the same soil type, the yield on the check plots was 80.6 bushels per acre. Thus, in many cases the different farms on the same soil type cannot be considered as replications, and it is desirable to obtain fairly precise results on each farm, in order to learn the specific effect of the treatments. However, each of these tests is not considered as a self-contained experiment, nor is a rigid interpretation by statistical methods applied to the data, although the experimental error is calculated and considered in arriving at conclusions. Observation of the data in any of these tests with consideration of other information on the soil, is the approach being followed in regard to interpretation.

Greenhouse Experiments

The soils for greenhouse studies consist of composite samples of surface soil from twenty distributed points in the case of each field selected. The soils are air-dried, passed through a sieve with one-half inch mesh, mixed, and placed in glazed gallon pots on a volume basis. Oats and alfalfa are seeded together in December and later thinned to seven plants of oats and ten of alfalfa per pot. Fertilizers are placed in the soil in a layer at a depth of two inches, oat seeds at a depth of one inch and alfalfa seeds at a depth of one-half inch. The treatments are randomized in each of three replications. The oat crop is harvested in the spring and during the summer three crops of alfalfa are obtained.

Several factors relating to greenhouse technique have been studied. Observations of the performance of crops under field conditions on the different soils are kept in mind in interpreting greenhouse data. In a general way, the trends of response to the different elements on the different soils have been similar under field and greenhouse conditions, although

TABLE 2.—AVERAGE YIELDS OF GRAIN FROM OATS ON DIFFERENT SOILS UNDER FIELD AND GREENHOUSE CONDITIONS

Soil	Greenhouse tests Check pots, 5 fields	Estimated field yields 1941-1947, excepting 1944	
	Yield in grams per pot	Number of fields	Yield in bushels per acre
Kars gravelly sandy loam	4.8	61	35
Castor silt loam	1.8	56	40
North Gower clay loam	3.3	71	43
Carp clay loam	3.8	105	47
Rideau clay	5.7	100	39

TABLE 3.—INCREASES IN GRAIN YIELDS FROM NITROGEN AND PHOSPHORUS TREATMENTS IN FIELD AND GREENHOUSE TESTS ON TWO SOILS

Kind of test	Treatments in pounds per acre*			Increases in grain yield			
				Castor silt loam (one farm)		North Gower clay loam (average two farms)	
	N	P_2O_5	K_2O	N	P_2O_5	N	P_2O_5
				%	%	%	%
Field	16	48	48	48	42	11	9
Greenhouse	16	40	40	82	673	21	74

* Elements applied singly and in each combination.

exceptions occur, and the degree of response may be of greater magnitude in the greenhouse in some cases. The variation in performance of some soils under field and greenhouse conditions is illustrated by data in Table 2.

On the Rideau clay and the Kars gravelly sandy loam, good grain yields have been produced in the greenhouse. The relatively higher rating of the Kars soil in the greenhouse than on the basis of field performance is probably the result of more favourable moisture conditions for this soil under greenhouse conditions. On the Castor silt loam, North Gower clay loam, and Carp clay loam, receiving no fertilizer, relatively poorer yields of oats have been produced in the greenhouse than might have been expected on the basis of yields in the field.

In field tests in 1946 on Castor silt loam and on North Gower clay loam, and in greenhouse tests on similar soils obtained in the fall of the same year from the same farms though on different fields, the oat crops responded to both nitrogen and phosphorus but not to potassium. The percentage increases in grain yields from nitrogen and from phosphorus treatments on these soils in the field and greenhouse tests are presented in Table 3. It is to be noted that, on these soils, phosphorus became more of a limiting factor in the greenhouse than in the field tests.

On the Kars gravelly loam, and Rideau clay, where good yields of grain were produced in the greenhouse (Table 2), the response to phosphorus was slight as will be shown later in this paper.

TABLE 4.—PHOSPHORUS CONTENT OF GRAIN FROM OAT CROP ON DIFFERENT SOILS IN THE GREENHOUSE

(All soils received 400 lb. per acre of 4-0-10 fertilizer)

Soil	Number of tests	Phosphorus in grain
		% P
Kars gravelly sandy loam	3	0 34
Castor silt loam	3	0 29
North Gower clay loam	3	0 29
Carp clay loam	3	0 28
Rideau clay	3	0 37

TABLE 5.—ROOT YIELDS FROM AN OAT CROP ON DIFFERENT SOILS IN THE GREENHOUSE

(Air-dry weights of roots, when vegetative top growth measured approximately 18 inches)

Soil	Treatments	
	4-0-10 (Grams of roots per pot)	4-10-10 (Grams of roots per pot)
Uplands sand	1 4	2 0
Rubicon sand	1 2	1 5
Kars gravelly sandy loam	1 4	1 7
North Gower clay loam	0 6	0 7
Carp clay loam	0 7	1 0
Rideau clay	0 5	0 7

TABLE 6.—EFFECT OF DIFFERENT SUBSOILS ON THE YIELDS OF OATS AND ALFALFA GROWN IN THE GREENHOUSE

(Yields based on six replications)

Subsoils	Grain grams per tile	Three crops of alfalfa grams per tile (air-dry)
Clay	11 5	9 6
Loam	16 0	14 5
Sand	8 6	10 5

Data in Table 4 indicate that the phosphorus content in the grain of oat crops grown in the greenhouse on Kars gravelly sandy loam and Rideau clay was higher than that of the grain produced on Castor silt loam, North Gower clay loam, and Carp clay loam. The foregoing results suggest the possibility that a limited supply of soil phosphorus may be a contributing factor to the poor performance of certain soils under greenhouse conditions.

The greater root growth occurring in soils of lighter texture, as shown in Table 5, may compensate to some extent for lower levels of nutrients in such soils. The data on each soil type were based on three tests on soil from different farms. The treatments were applied on the basis of 400 lb. of 4-10-10 per acre.

TABLE 7.—EFFECT OF DIFFERENT FERTILIZER TREATMENTS ON YIELDS OF OATS IN FIELD TESTS ON FOUR SOIL TYPES

(Yields in bushels per acre)

Soil	Number of tests 1944-1946	Average yields		Increases from 4 12-12		Average increases from fertilizer elements		
		Check	4 12 12*	Average	Maximum in any test	Nitrogen	Phosphorus	Potassium
Uplands sand	6	14	27	13	21	9	2	1
Rubicon sand	4	28	37	9	9	4	3	3
Castor silt loam	6	35	48	13	18	6	5	1
North Gower clay loam	4	46	52	6	16	5	3	−3

* Four hundred pounds per acre

In the application of greenhouse results to field problems the absence of subsoil in greenhouse tests is worthy of consideration. The effect of different subsoils on the yields of oats and alfalfa grown in the greenhouse on a uniform surface soil in tiles, containing clay, loam, and sand subsoils to a depth of two feet, is shown by the data in Table 6. The variation in yields indicates that the subsoils had an appreciable influence on the growth of these crops.

Comparisons of field responses to fertilizers with those obtained in the greenhouse, on soils from the same field experimental sites, are being made. In the one comparison available in 1947, both field and greenhouse tests, based on the same field on Castor silt loam, indicated the superiority of 8-12-4 and 8-8-8 ratios over a number of other fertilizer ratios, for an oat crop. In the field test the increases over the check were 19 and 17 bushels per acre, representing increases of 70 and 63 per cent for the 8-12-4 and 8-8-8 ratios, respectively. In the greenhouse test the increases over the check for the 8-12-4 and 8-8-8 ratios were 311 and 254 per cent, respectively. Although not a measure of the degree of response the greenhouse test has indicated the trend of response to be expected under field conditions.

Information on the reliability of greenhouse results, and on the different factors contributing to discrepancies between greenhouse and field results, should be valuable in the interpretation of greenhouse data in relation to field conditions. The effect of the presence of subsoils on the response of oats and alfalfa to fertilizer treatments applied to the surface soils, and the effects of air-drying of soils for a period of four weeks prior to seeding as followed in current greenhouse procedure, are factors being studied.

Laboratory Studies

The importance of combining laboratory studies with field and greenhouse work of the nature just outlined is widely recognized. In the past it has seldom been possible to bring this about in such an extensive study. Examination of the soils under investigation will supply a great deal of information which will be useful in interpreting some of the observations made, as well as giving fundamental results on the variation to be found between and within soil types. The determination of soil reaction, amounts

TABLE 8.—EFFECT OF FERTILIZER TREATMENTS ON OATS IN 1946, AND ON SUCCEEDING HAY CROP IN 1947, ON FOUR SOIL TYPES

(Grain in bushels per acre, and hay in pounds of dry matter per acre)

Soil	Farm	Yields				Increases from fertilizer elements					
		Check		4-12-12 400 lb. per ac.		Nitrogen		Phosphorus		Potassium	
		Grain	Hay	Grain	Hay	Grain	Hay	Grain	Hay	Grain	Hay
Uplands sand	*Quinn	14	2920	35	—	15	−576	3	347	2	526
Rubicon sand	Hawkins	30	2316	39	2927	5	−193	3	466	3	394
Castor silt loam	Waddell	11	1360	22	2142	5	−171	5	888	−1	104
North Gower clay loam	Kenny	50	2001	66	3291	9	− 12	9	1098	−2	128

* The hay yield data for the 4-12-12 treatment on this farm were not reliable and were discarded

of organic matter, nitrogen, phosphorus and exchangeable bases, and mechanical composition, should give a more detailed picture of the soils with which the agronomist is working. On the other hand, results of controlled experiments in field and greenhouse can be extremely useful in supplementing laboratory investigations. For example, the value of studies on soil colloids and soil organic matter is very much enhanced when results can be compared with the agronomic behaviour of the soils in question.

In the work under discussion, measured response to fertilizer applications is being compared with determinations of so-called "available" phosphorus and potassium by a variety of methods. Many procedures have been suggested for estimating the availability of these plant nutrients in soil and some have been used fairly extensively with more or less success. However, the universal applicability of such methods is questionable. Tests found suitable in one region may be entirely unsuitable in another and methods which will work on acid soils, for example, may give results leading to erroneous conclusions on alkaline soils. What appears to be lacking is a sufficiently large volume of data for any of these methods on a wide variety of our soil types on which measured response to applications of phosphorus and potassium has been obtained. This is being attempted on the Carleton County soils and will be extended to other areas as time and opportunity permit.

DISCUSSION OF RESULTS FROM FIELD, GREENHOUSE AND LABORATORY TESTS ON DIFFERENT SOIL TYPES

Response of Oats and Hay Crops to N, P and K in Field

Field tests relating to fertilizer treatments for oats and subsequent hay crops were conducted on four soil types from 1944 to 1946, inclusive. Nitrogen, phosphorus, and potassium were applied alone and in combination, at the rates represented for each element by 400 lb. per acre of a 4-12-12 fertilizer. The response of the crop to each of the elements N, P and K represented the increase in yield due to that element when used alone and with each of the other elements. Thus, for nitrogen, the increase

TABLE 9.—RESPONSE OF OATS AND ALFALFA TO NITROGEN, PHOSPHORUS, AND POTASSIUM ON DIFFERENT SOIL TYPES, IN THE GREENHOUSE

(Grain in grams per gallon pot, and alfalfa as total air-dry weight of three cuttings in grams per pot)

Soil*	Yields				Increases from fertilizer elements					
	Check		4-10-10		Nitrogen		Phosphorus		Potassium	
	Oats	Alfalfa	Oats	Alfalfa	Oats	Alfalfa	Oats	Alfalfa	Oats	Alfalfa
Uplands sand	1.8	11.5	4 7	12.4	2.3	−4.3	0.2	0.2	0.3	3.3
Rubicon sand	3.7	10.8	5.1	22.7	1.3	−1.1	0.2	6.0	0.0	6.8
Kars gravelly sandy loam	6.0	26.9	8.0	33.7	2.3	−1.7	−0.5	3.2	−0.2	5.2
Grenville loam	4.4	19.7	8.9	29.0	1.3	0.1	3.1	6.2	0.1	0.7
Manotick sandy loam	3.6	12.5	8.1	20.7	1.4	−1.6	2.6	6.3	0.0	3.0
Castor silt loam	1.4	7.2	5.6	15.4	1.4	−1.1	2.9	5.7	0.1	4.7
Osgoode loam	4.2	15.4	7.8	23.7	1.7	−1.6	2.2	7.9	−0.5	1.9
Carp clay loam	3.9	18.5	7.7	25.9	2.0	−1.5	1.9	8.3	0.3	0.8
North Gower clay loam	3.4	11.0	7 9	23.6	1.1	−1.1	3.6	12 4	−0.3	0.9
Rideau clay	5.1	25.3	7.8	25.9	2.1	−1.8	0.8	3.0	−0.2	−0.2

* Each soil type represented by tests on soil from three farms.

of the N-treated plot over the check was determined, also that for NP over P, for NK over K, and for NPK over PK. The average of these has been taken as a measure of the response to nitrogen treatments. Similar calculations were made for the elements P and K. The results obtained in 1944 and 1945 were from unreplicated treatments in plots 15 feet in width and extending the length of the fields, but in 1946 the treatments were replicated three times, using the design referred to earlier in the discussion of technique. A summary of the effect of treatments on yields of oats is presented in Table 7. Although variations in results occurred between tests on the same soil type, and in different years which are not shown in Table 7, the data indicate an increase in grain yields from nitrogen and from phosphorus, with a trend for greater increases from nitrogen than from phosphorus, especially on the excessively drained Uplands sand. There was little response by the oat crop to potassium except on Rubicon sand, where a small but consistent trend for response to this element occurred in each of the four tests. The trends for response to nitrogen were more consistent in regard to the different tests on the same soil type than those for phosphorus. The yields for the check and the 4-12-12 treatment show the variation between soil types in regard to production of oats and indicate the magnitude of increases in yields from complete fertilizer on the different soils.

The hay mixture seeded in the field tests consisted of timothy, red clover, alsike and alfalfa. To illustrate the different response of this crop from that of oats, to the treatments applied at the time of seeding, the data on hay yields for 1947 on one test on each of the four soil types will be discussed in relation to the yields of oats obtained in these tests in 1946.* From Table 8 it may be noted that on Castor silt loam and North Gower clay loam, where oats responded to phosphorus but not to potassium, appreciable increases in hay yields from phosphorus treatments and trends

* Sampling for hay yields was done by the Division of Forage Plants, Experimental Farms Service

towards small increases from potassium were obtained. On Uplands sand and Rubicon sand, where trends in favour of a slight response to phosphorus and to potassium by the oat crop occurred, the hay yields showed a response to each of these elements.

Nitrogen treatments which increased grain yields in all tests, resulted in lower hay yields. However, the 4-12-12 treatments produced appreciably higher yields than the checks. The higher yields of grain may have been responsible for the decreased hay yields. In an experiment conducted for four years by the Field Husbandry Division at Ottawa, in which oats were seeded at 1½, 2, 2½, and 3 bushels per acre, the yields of grain increased directly with rate from 72 bushels per acre at the lowest rate to 73, 80, and 85 bushels per acre for each of the respective rates. The yields of the first year succeeding alfalfa decreased directly with the increase in yield of oats, the decrease from the lowest rate to the highest being 280 lb. of dry matter.

Response of Oats and Alfalfa to N, P, and K in Greenhouse

In 1946, greenhouse studies to measure the response to fertilizer elements by grain and legumes on Carleton County soils were undertaken along the lines reported in 1945 (1). Tests on soil from three farms on each of ten soil types were conducted in 1946-47, and a similar set of tests on soil from different farms was carried out during 1947-48. A continuation of this work on soils from a sufficient number of fields distributed so as to represent each soil type will be very useful in evaluating chemical soil tests.

In Table 9, the responses of oats and alfalfa in the greenhouse to nitrogen, phosphorus and potassium, where each element was applied alone and in combination at the respective levels found in a 4-10-10 fertilizer at 400 lb. per acre, are given as averages for three farms on each soil type, sampled in 1946. The increases in yield from each element were calculated as illustrated in the discussion of field results. In general, oats responded to nitrogen and phosphorus but not to potassium, whereas alfalfa yields showed increases from phosphorus and potassium but decreases from nitrogen. In regard to the response to the minerals, there were variations between soil types. The oat crop showed no response to phosphorus on the Uplands sand, Rubicon sand and Kars gravelly sandy loam, and only slight response to this element on the Rideau clay. With the exception of the Rubicon sand (where soil from one farm gave different results), the alfalfa yields on these four soils showed less response to phosphorus than obtained on the other soils, there being no response on the Uplands sand. The alfalfa on Uplands sand, Rubicon sand and Kars gravelly sandy loam, responded to potassium more than to phosphorus, but on the other soils, phosphorus produced greater increases than potassium. The alfalfa on Rideau clay showed no response to potassium, and on the Grenville loam, Carp clay loam, and North Gower clay loam the response was slight. These trends were similar to those reported in the earlier paper (1) and in a general way followed the field observations where such were available.

Laboratory Results on Soil Samples

In texture, the soils under study varied from light sands to heavy clays. The lightest soils, Uplands and Rubicon, contained over 80 per cent sand; intermediate types such as Castor, Osgoode, Carp, North

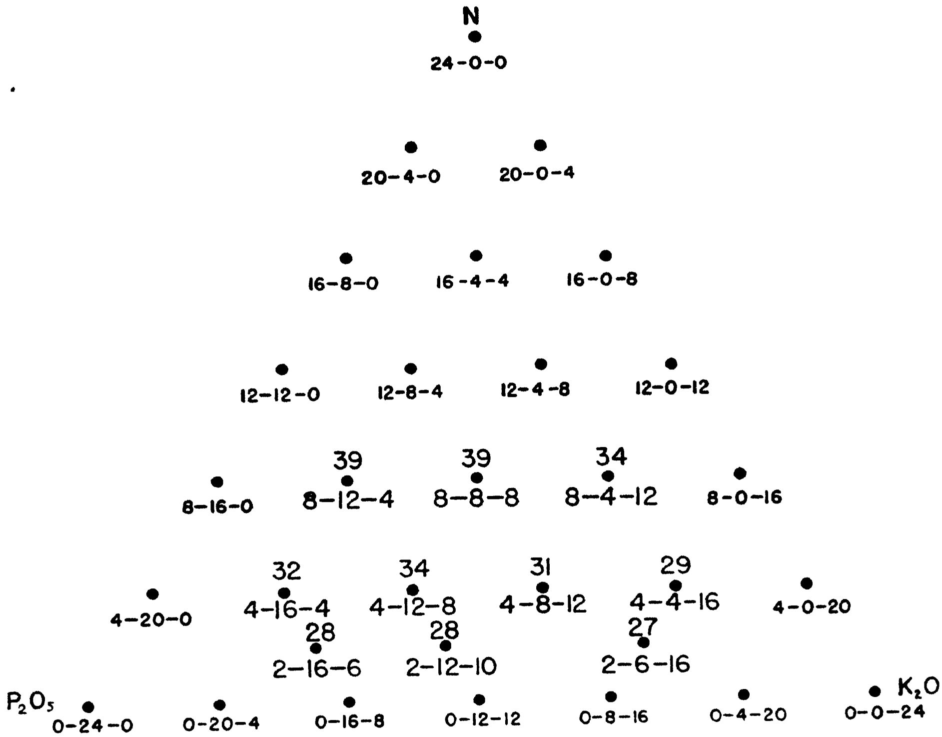

FIGURE 1. Yields of oats on Castor silt loam, receiving fertilizer ratios, located on Schreiner Triangle. Each yield is average in bushels per acre of grain, from rates of 200 and 400 lb. per acre of fertilizers. The yield for the check plots was 22 bu. per acre.

Gower, contained 40 per cent to 50 per cent silt; and the heaviest type, the Rideau, had over 40 per cent clay. The three samples from some types (Uplands, Osgoode, North Gower) were quite uniform in mechanical composition; those from certain other types (Kars, Manotick) were quite variable. This might be expected in the case of the last two soils on the basis of descriptions of their occurrence.

In reaction, the soils varied from moderately acid (pH 5.8) to strongly alkaline (pH 8.3). Of the 30 samples tested, 14 had pH values of 7.2 or over. All samples of Uplands and Rideau were acid; all samples of Grenville and North Gower were alkaline. In the case of most of the other types, the reactions of the samples ranged from acid through neutral to alkaline.

The organic matter content of these soils also showed considerable variation, as measured by nitrogen content and loss on ignition. The amount of nitrogen found ranged from 0.06 per cent to 0.37 per cent. The amount of organic matter is to a certain extent dependent on the system of farm management and might be expected to be higher in the soils from farms where considerable manure has been applied over a period of years. Nevertheless, there were some pronounced differences between soil types. The Uplands sand samples contained the lowest amounts whereas the highest levels were found in the Carp and North Gower soils.

The total phosphorus content varied from 0.11 to 0.33 per cent. P_2O_5 and there was considerable variation within each soil type. No analyses have yet been made to determine the amounts of phosphorus present in the organic form but this is information that should be obtained.

The amount of readily soluble phosphoric acid was determined by extraction with a solution of $KHSO_4$ at pH 2.0, as described by Lohse and Ruhnke (3). According to the standards given by the authors of the methods, not more than two of the samples examined would be considered deficient in this constituent; in fact, most of them would appear to be extremely well supplied. Nevertheless, as has been shown, response to applications of phosphorus has been obtained in the majority of cases.

Exchangeable bases were determined by extraction with neutral normal ammonium acetate solution. With the exception of the light textured soils, the samples examined were in general well supplied with exchangeable calcium and magnesium. Factors which affected the amounts of these bases were texture, reaction and organic matter content. The amounts of exchangeable potassium found were, on the whole, somewhat lower than might be expected. Two-thirds of the samples had less than 160 lb. K per acre in this form. The Rideau and Carp types contained the largest amounts; the Grenville appeared to be reasonably well supplied.

A considerable amount of information on the composition of samples from various soil types was presented in the Soil Survey Report (2). Further information obtained on samples used in greenhouse studies will supplement that previously obtained and, over a period of time, a very good picture of the variation between and within soil types in this area will be obtained.

FERTILIZER FORMULAE FOR OATS AND HAY CROPS

As a result of the experimental results discussed above, different ratios of nitrogen, phosphorus and potassium, based on the Schreiner Triangle (4) were applied in field tests in 1947, for oats seeded to hay on four soil types. The ratios, each of which contained the same total percentage of the three major elements, were randomized and replicated two and in some cases three times, except that they were applied at a different rate in each block, the rate effect being confounded with block effect. Since grain and hay crops respond differently, the most desirable ratios for grain seeded to hay cannot be assessed until hay yields are obtained. However, to illustrate the scheme of treatments, the average yields of grain from the two rates in a test on Castor silt loam are shown in Figure 1. In this test, the yields of grain increased with increase in per cent nitrogen in the ratios, and there was a slight trend in favour of ratios higher in phosphorus than potassium. The 8-12-4 and 8-8-8 ratios produced the highest yields, the increase over the check being 17 bushels per acre.

SUMMARY

In this paper, an attempt has been made to outline the approach to fertility studies on soil types that is being followed by the Divisions of Chemistry and Field Husbandry at Ottawa. The plan is to integrate field, greenhouse and laboratory studies very closely in order to obtain as complete a picture of the soils under investigation as possible. It is expected that the considerable amount of information so obtained will be most useful in extending the work to other soil types in other areas.

In the field, simple tests are laid out on private farms and yield data obtained thereon are carefully studied. The number of such tests which can be handled satisfactorily is limited. In the greenhouse, the investigation can be extended to include soil samples from many more individual farms and different farms can be sampled each year. With such a number of samples available for laboratory investigation, a considerable volume of data on the constitution of the soils in the county is being obtained. Thus soil composition, measurement of "available" constituents and response to fertilization can be correlated.

Soil samples from areas where field experiments are conducted are also brought into the greenhouse in an attempt to correlate response to fertilizer applications under these different conditions. In this connection, various points in greenhouse technique are being studied.

In general, from both field and greenhouse results, it appears that, on the Carleton County soils, grain responds to applications of nitrogen and phosphorus, whereas legumes respond to additions of phosphorus and potassium. It has been observed that a large grain yield may cause a reduced yield in the subsequent hay crop.

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THIRTY-FIVE YEARS OF WEATHER RECORDS AT SAINTE-ANNE-DE-LA-POCATIÈRE[1]

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The importance of meteorological observations in agricultural research is widely recognized. Unfortunately the data accumulated through the years are not always readily available in a form most valuable to agriculturists. Since meteorological data have been recorded at the Experiment Station, Sainte-Anne-de-la-Pocatière, for a period of 35 years, it was decided that a study based on these data would be of value to various research workers.

The meteorological data have been tabulated and analysed statistically so as to bring out the characteristics of the climate. Statistical analysis of meteorological data was widely used by Hopkins (3, 4, 5, 6, 7, 8) and by others. Dingle (2) has recently emphasized the importance of using the frequency distribution as a supplement to the mean. The standard deviation was computed according to the method set forth by Snedecor (9). Since the data were obtained from a single station only, comparisons can be made by referring to Villeneuve (11).

LOCATION AND TOPOGRAPHY

The meteorological station of Sainte-Anne-de-la-Pocatière is in latitude 47° 22′ North and longitude 70° 22′ West of Greenwich, at 100 feet above sea level, and about two miles south of the St. Lawrence River. The Station is surrounded on the south side by a ridge of an elevation of some 300 feet.

The location and surroundings of the instrument shelter are shown in Figure 1. Free movement of air around the instruments might be restricted to some degree especially on the south and east sides. Maple trees on the north side may affect the movement of air during the summer.

PRECIPITATION

Precipitation is measured in hundredths of an inch twice daily from a rain gauge fixed on a wooden pillar. The precipitation data were computed and analysed so as to provide further information on the frequency, duration and intensity of rainfall, the importance of which has already been pointed out by Blumenstock (1).

The total monthly and annual precipitation for each year is given in Table 1. The total annual precipitation varies from 20.58 inches to 48.21 inches, with a mean of 36.66 inches. Variability from year to year is high, especially during the summer. The precipitation, however, is fairly well distributed through the months and seasons. A slightly greater amount of rainfall occurred during the summer, as shown in Figure 2. The wettest months were September and July. A gradual increase in the amount of

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TABLE 1.—CHARACTERISTICS OF THE MONTHLY PRECIPITATION, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

(Rain and melted snow, in inches)

Month	Mean	Range	Standard deviation
January	2.82	0.70 - 6.50	1.33
February	2.63	0.55 - 7.91	1.53
March	2.63	0.80 - 6.29	1.33
April	2.72	0.86 - 6.35	1.36
May	3.12	1.16 - 6.88	1.34
June	3.46	0.92 - 7.68	1.78
July	3.73	0.64 - 6.73	1.62
August	3.28	0.75 - 9.21	1.69
September	3.80	0.65 - 7.38	1.80
October	3.29	0.60 - 7.15	1.53
November	2.72	0.74 - 7.76	1.54
December	2.46	0.60 - 6.11	1.45
Year	36.66	20.58 - 48.21	6.00

TABLE 2.—CHARACTERISTICS OF THE MONTHLY SNOWFALL IN INCHES, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	24.0	6.5 - 49.0	11.9
February	23.2	5.5 - 64.0	12.3
March	20.1	0.4 - 47.5	11.6
April	9.2	0.0 - 31.0	8.1
May	0.4	0.0 - 4.0	0.8
June	0.0	0.0 - 0.0	0.0
July	0.0	0.0 - 0.0	0.0
August	0.0	0.0 - 0.0	0.0
September	0.0	0.0 - 0.0	0.0
October	1.5	0.0 - 8.0	2.5
November	10.1	0.0 - 29.8	7.4
December	18.8	5.0 - 45.0	12.2
Year	107.2	50.0 - 205.5	32.9

precipitation can be observed in Figure 3 for the period 1913-47. This increase is perhaps due to the high of a long cycle, and not to a change in the climate.

Table 2 shows the annual and monthly amount of snowfall. The average annual snowfall is 107.2 inches ranging from 50.0 inches to 205.5 inches. Variability is low from year to year, if the amount of snow is converted into its water equivalent, one-tenth of an inch. The greatest amount of snowfall usually occurred in January and February. The average annual snowfall represents 28.2 per cent of the total precipitation. Snow cover does not always give as good a protection to perennial plants as the annual snowfall seems to indicate, on account of considerable drifting. Highly significant correlation ($r = 0.57$; D.F. $= 33$) was found between the precipitation of July and September. There was no relationship between any other months.

TABLE 3.—AVERAGE NUMBER OF RAINY DAYS PER MONTH, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
April	9.7	3 - 17	3.5
May	10.5	4 - 16	3.2
June	11.0	3 - 18	3.4
July	11.5	3 - 17	3.2
August	10.1	4 - 18	3.4
September	10.6	4 - 20	3.7
October	11.2	5 - 19	3.7

The number of days per month in which a measurable amount (one-hundredth of an inch) of precipitation fell are recorded in Table 3 for each of the seven months from April to October. Differences between months are not great. Stormy days, that is days with rain or snow, are somewhat less numerous during the winter than during the summer as shown in Figure 4.

The frequency of occurrence of rainless and rainy periods of specified length are given in Tables 4 and 5, respectively. The procedure followed to calculate the random expected frequencies (headed expected) and to analyse the deviations of the observations from the expected values was the same as expounded by Hopkins (5). There was an excess of sequences

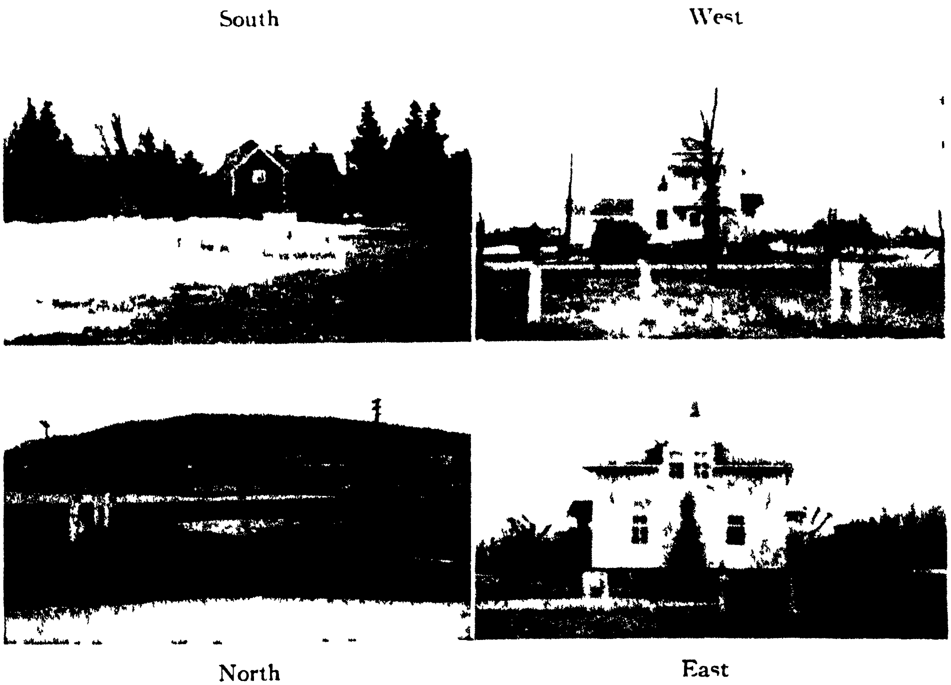

FIGURE 1. Position and surroundings of the instrument shelter when facing south, west, north and east.

TABLE 4.—FREQUENCY OF OCCURRENCE OF RAINLESS PERIODS OF SPECIFIED LENGTH, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Rainless period, days	April		May		June		July		August		September		October	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
0	139	109.8	155	124.1	166	141.1	172	147.5	134	117.5	147	129.7	172	141.6
1	59	74.2	73	81.9	87	89.4	76	93.0	66	79.0	63	83.9	70	90.4
2	38	50.2	40	54.0	37	56.6	51	58.6	56	53.2	58	54.2	55	57.8
3	28	33.9	28	35.7	31	35.8	23	37.0	31	35.8	46	35.1	37	36.9
4	26	23.0	21	23.5	24	22.7	27	23.3	17	24.1	14	22.7	16	23.6
5	12	15.5	15	15.5	12	14.4	19	14.7	21	16.2	8	14.7	11	15.1
6	8	10.5	8	10.2	3	9.1	10	9.3	12	10.9	10	9.5	12	9.6
7	9	7.1	5	6.8	6	5.8	9	5.8	6	7.3	3	6.1	5	6.1
8	6	4.8	4	4.5	6	3.6	5	3.7	2	4.9	7	4.0	2	3.9
9	0	3.2	6	2.9	1	2.3	3	2.3	3	3.3	3	2.6	0	2.5
10	3	2.2	1	1.9	3	1.5	1	1.5	4	2.2	4	1.7	2	1.6
11	3	1.5	2	1.3	2	0.9	1	0.9	3	1.5	2	1.1	3	1.0
12	2	1.0	4	0.8	3	0.6	1	0.6	1	1.0	1	0.7	2	0.6
13	0	0.7	1	0.6	1	0.4	0	0.4	0	0.7	0	0.4	1	0.4
14	1	0.5	0	0.4	1	0.2	1	0.2	0	0.5	0	0.3	1	0.3
15	2	0.3	0	0.2	0	0.1	1	0.1	1	0.3	1	0.2	1	0.2
16	1	0.2	1	0.2	0	0.09			1	0.2			0	0.1
17	1	0.1	0	0.1	1	0.06			0	0.1			0	0.07
18	0	0.09	0	0.07	0	0.04			1	0.09			1	0.04
19	0	0.06	0	0.05	0	0.02							1	0.03
20	0	0.04	0	0.03	0	0.01								
21	0	0.03	0	0.02	0	0.01								
22	0	0.02	0	0.01	0	0.006								
23	0	0.01	0	0.009	0	0.004								
24	1	0.009	1	0.006	1	0.002								
χ^2	25.324†		19.344*		24.673†		18.155*		13.284		19.864*		20.301*	

* Exceeds 5 per cent point.
† Exceeds 1 per cent point

TABLE 5.—FREQUENCY OF OCCURRENCE OF SEQUENCES OF DAYS WITH RAIN, SAINTE-ANNE-DE-LA-POCATIÈRE 1913-1947

Number of consecutive days with rain	April		May		June		July		August		September		October	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
0	524	488.2	497	470.5	447	421.2	465	433.7	505	488.5	458	440.4	473	441.3
1	102	158.1	125	160.0	133	154.4	125	160.3	142	159.8	132	155.6	132	159.4
2	61	51.2	55	54.4	43	56.6	59	59.2	48	52.3	60	55.0	49	57.6
3	26	16.6	22	18.5	21	20.7	17	21.9	17	17.1	17	19.4	17	20.8
4	5	5.4	9	6.3	11	7.6	9	8.1	7	5.6	7	6.9	7	7.5
5	3	1.7	3	2.1	4	2.8	9	3.0	5	1.8	5	2.4	8	2.7
6	1	0.6	0	0.7	4	1.0	2	1.1	1	0.6	0	0.8	2	1.0
7			1	0.2	0	0.4	1	0.4	1	0.2	2	0.3	0	0.3
8			0	0.08	2	0.1	1	0.1					2	0.1
9			0	0.03									0	0.05
10			1	0.01									1	0.02
χ^2	16.973†		12.068*		14.838*		17.939†		6.996		6.279		14.853*	

* Exceeds 5 per cent.
† Exceeds 1 per cent.

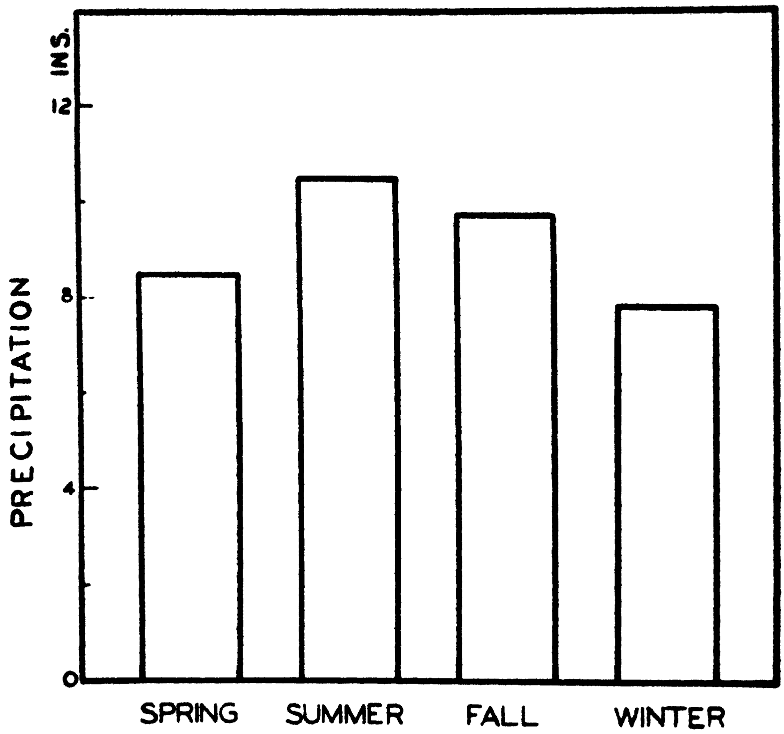

FIGURE 2. Seasonal distribution of the total precipitation in inches.

of zero dry days and of sequences of zero rainy days, and a deficiency of rainless periods of one to three days, similar to the condition found by Hopkins (5) in Western Canada. The statistical significance of the values χ^2 confirmed the previous findings of Hopkins (5) that rainy or rainless days do not in general occur entirely at random, but that the same kind of weather tends to persist over successive days. These statistics were used to estimate the expectation of rainless and rainy periods given in Table 6. Long periods of drought are expected less often in July and more often in April. Long rainy periods can be expected more often in October, June and July, and less often in April. These occurrences of rainy days tend to make haying operations somewhat more difficult.

The intensity of monthly rainfall expressed in daily rate is shown graphically in Figure 5 for each month from April to October. In general a little more than 50 per cent of the monthly rainfall fell at a rate of 0.01-0.20 inch per day. Rainfall intensity appears to be higher in September and lower in April. These data indicate that water run-off is more likely to occur in September, and possibly in July, than in other months, except possibly in the spring at the time when snow is melting.

Precipitation has another important bearing on the harvesting of crop for seed production. The amount of rainfall and the frequency of rainless periods seem to indicate that handling of crops for seed production should preferably be done in August. Periods of drought during the summer, and especially in August, decrease the productivity of pastures. The recurrence of these dry periods points out to the plant breeder the importance of drought resistance in clover improvement especially.

TABLE 6.—EXPECTED FREQUENCY OF OCCURRENCE OF RAINLESS AND RAINY PERIODS OF SPECIFIED LENGTH, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Length of periods, days	Expected frequency of occurrence, once in:						
	April	May	June	July	August	September	October
Rainless periods							
5 or more	0.7 yr.	0.7 yr.	0.9 yr.	0.7 yr.	0.6 yr.	0.9 yr.	0.8 yr.
10 or more	2.5	3.5	3	7	3	4	3
15 or more	7	17	17	35	12	35	12
20 or more	35	35	35	>35	>35	>35	>35
25 or more	>35	>35	>35	>35	>35	>35	>35
Rainy periods							
4 or more	4	2 5	1.7	1.6	2.5	2.5	1.7
5 or more	9	7	3.5	3	5	5	3
6 or more	35	17	6	9	17	17	7
7 or more	>35	17	17	17	35	17	12
8 or more	>35	35	17	35	>35	>35	12

TABLE 7.—CHARACTERISTICS OF THE MONTHLY MEAN TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	10 8	0.9 - 21 1	4.2
February	12.5	2.9 - 18 8	3.8
March	23 7	13.0 - 31.8	4.3
April	36.3	29.5 - 43.2	3.4
May	49.1	40.6 - 54 4	3.3
June	59.2	52.6 - 65.5	2.6
July	65.0	59.7 - 72.4	2.7
August	62 8	56.7 - 69 0	2.9
September	54 3	46.0 - 59 3	3 0
October	44.1	37.9 - 50.7	2.8
November	30 7	21.7 - 36.8	3.6
December	15 9	6.8 - 27.3	4 2
Year	38.7	34.9 - 41.6	1.6

TEMPERATURE

The highest and lowest daily temperatures are read from a mercurial maximum thermometer and alcohol minimum thermometer respectively. The daily mean temperature is found by averaging the highest and lowest temperatures. The monthly mean temperature is the sum of these mean temperatures for a month divided by the number of days of the month.

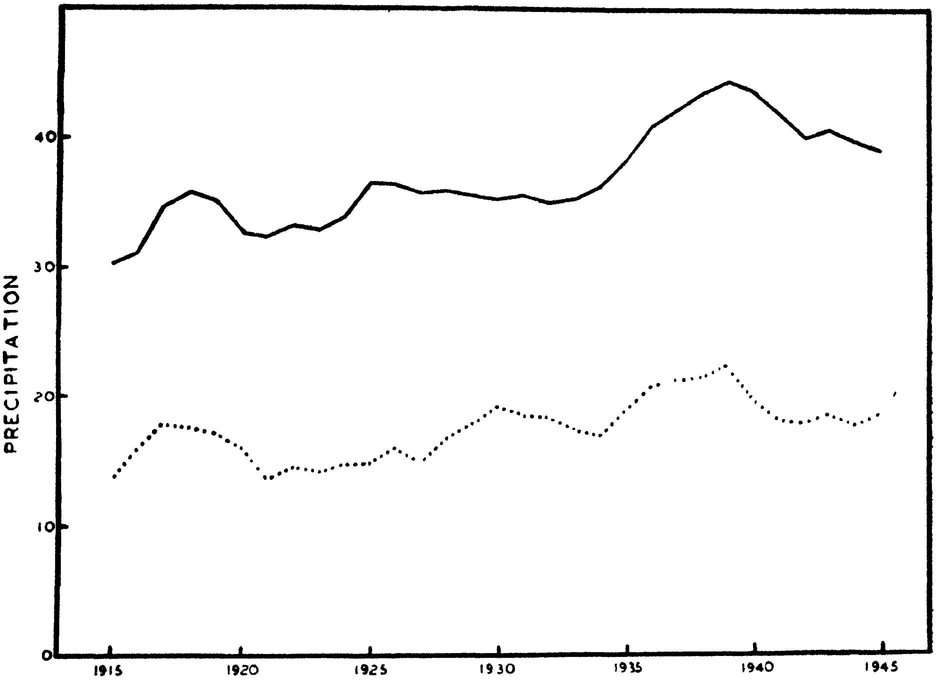

FIGURE 3. Five-year moving average of the total annual precipitation in inches (*solid line*) and of the amount of rainfall during the season of vegetation (May 1 to Sept. 30) (*dotted line*) from 1913 to 1947.

The monthly and annual mean temperatures are recorded in Table 7. The mean annual temperature is 38.7 degrees F. The variation from year to year of the annual mean temperature is rather small as indicated by a standard deviation of 1.6 degrees. The coldest month is January, the monthly mean temperature being 10.8 degrees F. July is the warmest month with a monthly mean temperature of 65 degrees F. The variation in the monthly mean temperatures is small during the summer and high during the winter, apparently as a consequence of the nearby large body of water which is frozen out during part of the winter. Similar features characterize the monthly mean maximum temperatures given in Table 8, and to some extent, the monthly mean minimum temperatures recorded in Table 9. The annual range of mean monthly temperature, which is the difference between the mean monthly temperature in July and the mean monthly temperature in January, is 54.2 degrees F.

Extreme monthly maximum and minimum temperatures are recorded in Tables 10 and 11, respectively. The lowest temperature recorded at Sainte-Anne-de-la-Pocatière since 1913 has been −33 degrees F. and the highest temperature 95 degrees F. The mean maximum temperature in July is 87.3 degrees F. and the mean minimum temperature in January is

TABLE 8.—CHARACTERISTICS OF THE MONTHLY MEAN MAXIMUM TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	19.4	7.4 – 31.2	4.8
February	21.9	12.5 – 30.5	4.3
March	32.8	21.8 – 41.1	4.4
April	45.1	36.7 – 54.5	4.3
May	60.2	49.1 – 69.0	4.3
June	70.9	66.6 – 77.1	2.8
July	76.3	71.5 – 84.4	2.4
August	74.2	68.3 – 78.3	2.4
September	65.4	51.7 – 72.5	3.5
October	53.1	45.3 – 60.6	3.4
November	37.9	29.6 – 45.2	3.6
December	23.7	13.6 – 33.4	4.5
Year	48.4	44.1 – 51.8	1.8

TABLE 9.—CHARACTERISTICS OF THE MONTHLY MEAN MINIMUM TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	2.6	–10.8 – 12.6	4.6
February	3.1	– 6.6 – 10.3	4.2
March	14.7	4.3 – 24.9	5.7
April	27.6	18.6 – 37.9	3.9
May	38.1	27.2 – 45.1	2.9
June	47.5	37.0 – 54.2	3.4
July	53.7	45.9 – 65.0	3.8
August	51.4	40.6 – 61.3	4.4
September	43.3	34.9 – 50.0	3.8
October	35.2	29.1 – 40.9	2.7
November	23.8	13.8 – 31.9	4.5
December	8.0	– 2.0 – 21.1	4.8
Year	29.0	23.9 – 31.8	2.0

TABLE 10.—CHARACTERISTICS OF THE EXTREME MONTHLY MAXIMUM TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	39.4	28 – 50	5.5
February	37.2	12 – 46	6.2
March	48.4	38 – 61	6.5
April	63.8	50 – 82	8.7
May	78.8	69 – 88	5.3
June	85.4	78 – 95	4.4
July	87.3	82 – 94	3.2
August	85.5	80 – 93	3.4
September	80.8	72 – 89	4.5
October	70.1	58 – 80	5.4
November	57.6	43 – 70	7.2
December	41.1	32 – 55	5.6
Annual maxima	89.3	84 – 95	2.8

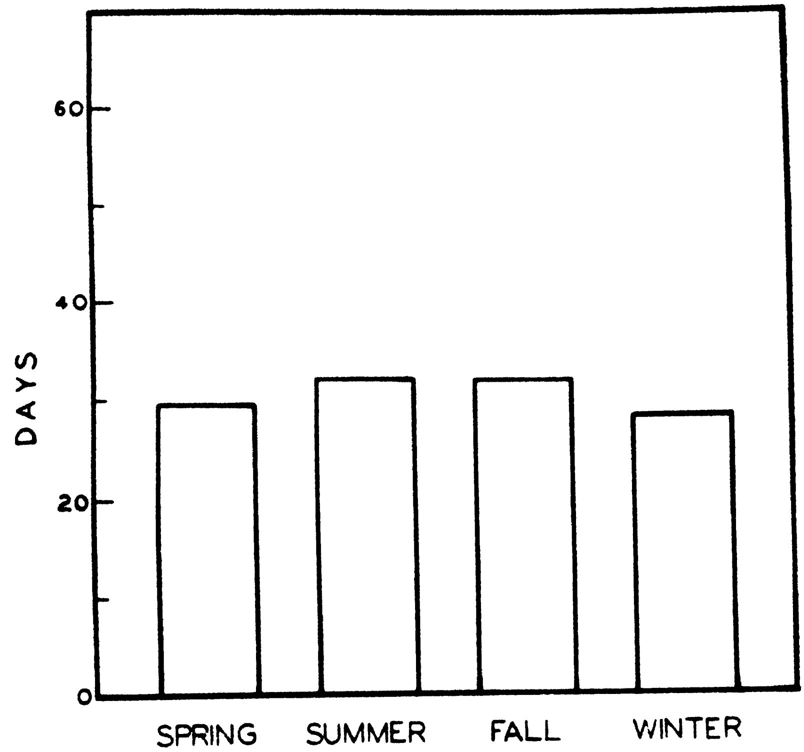

FIGURE 4. Mean seasonal frequency of stormy days.

−18.1 degrees F., thus giving a range of mean extreme temperature of 105.4 degrees. Temperatures below freezing-point have been recorded for every month of the year during the period 1913-1947.

Table 12 gives the monthly mean of the daily range of temperature. The daily range of temperature is higher during the summer months as a consequence from a greater solar radiation.

TABLE 11.—CHARACTERISTICS OF THE EXTREME MONTHLY MINIMUM TEMPERATURE, SAINTE ANNE DE LA POCATIERE, 1913-1947

Month	Mean	Range	Standard deviation
January	−18.1	−32 – −6	6.7
February	−15.5	−35 – −4	7.3
March	−5.6	−19 – 18	8.3
April	13.2	−1 – 24	5.9
May	27.8	19 – 35	3.3
June	35.6	23 – 43	4.3
July	42.6	30 – 53	4.2
August	39.5	28 – 45	3.4
September	30.6	18 – 36	3.7
October	23.7	10 – 31	4.5
November	6.1	−10 – 22	7.4
December	−12.7	−27 – 1	7.4
Annual minima	−21.0	−33 – −10	5.7

TABLE 12.—CHARACTERISTICS OF THE MONTHLY MEAN OF DAILY RANGE OF TEMPERATURE SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	17.3	5.8 – 29.1	5.0
February	18 8	12.4 – 32.7	3.4
March	17.7	3.5 – 29.8	4.6
April	17.5	6.2 – 29.8	4.5
May	22.1	14.1 – 31.9	3.5
June	23.3	18.0 – 31.2	3.3
July	22.6	14.8 – 31.8	3.4
August	22.8	15.4 – 33.3	4.2
September	22.1	11.3 – 31.2	4.2
October	17.8	13.6 – 26.0	2.9
November	14.6	9.3 – 28.3	3.9
December	15.7	9 2 – 30.0	3.8
Year	19.2	16.7 – 25.1	2.0

TABLE 13.—FROST DATA, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

	Mean	Range	Standard deviation
Last killing frost in spring	May 18	Apr. 27-June 4	10.3
First killing frost in fall	Sept. 28	Sept. 7-Oct. 30	10.0
Length of frost-free period in days	132.5	103 – 166	15.5

TABLE 14.—CHARACTERISTICS OF SUNSHINE RECORDS, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Per cent of possible	Hours of sunshine		
		Mean	Range	Standard deviation
January	31.6	87.5	56.5 – 116.3	15.7
February	38.0	109.4	61.0 – 159.4	21.6
March	38.7	142.1	105.6 – 213.2	25.9
April	41.1	168.8	112.2 – 236.5	33.4
May	44.3	207.4	141.6 – 287.1	38.8
June	44.4	211.1	134.1 – 275.2	37.2
July	52.2	250.2	170.2 – 293.8	26.8
August	51.9	227.9	175.3 – 278.0	29.8
September	42.2	157.9	87.3 – 213.1	32.4
October	33.7	112.8	61.4 – 174.5	28.1
November	25.5	71.6	36.2 – 109.3	19.8
December	26.6	69.9	44.5 – 103.0	15.6
Year	40.8	1816.6	1489.1 – 2030.7	134.7

Temperature data indicate that Sainte-Anne-de-la-Pocatière shows a slight tendency towards a marine climate. The equalizing effect on temperature of the St. Lawrence River is apparent principally during the summer.

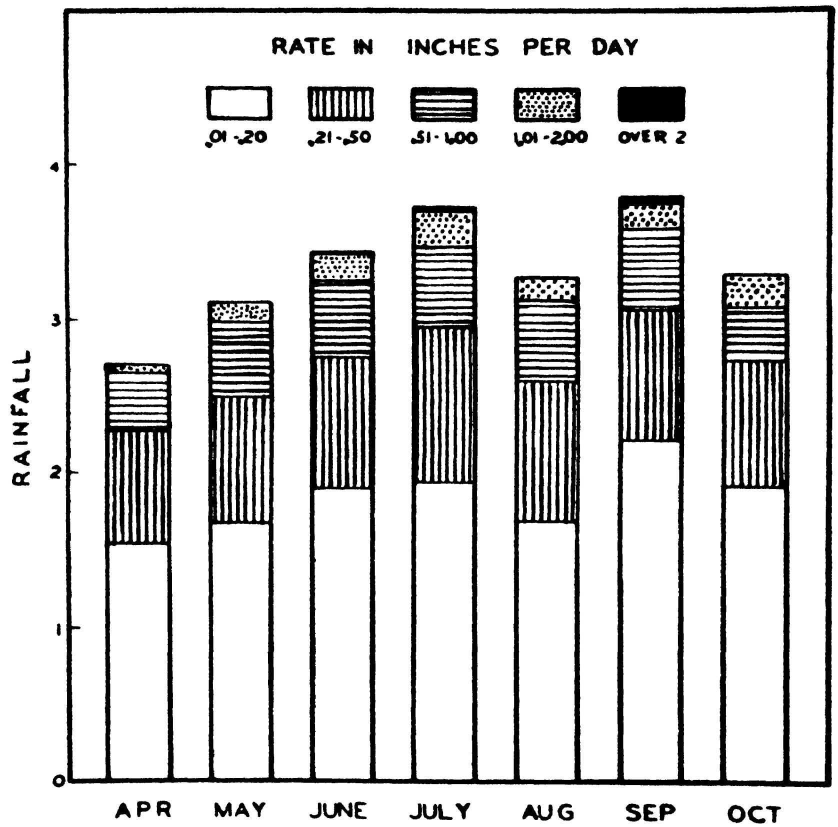

FIGURE 5. Rainfall amounts in inches falling at specified intensities, showing monthly variation from April to October, 1913-1947.

The frost-free period is the average number of days between the last frost in the spring and the first frost in the fall. Temperature of 32 degrees F. was used as a criterion of killing frost. Data relative to the length of the growing season are summarized in Table 13. The average length of the frost-free period is 132.5 days with a standard deviation of 15.5 days. The shortest season had 103 days and the longest one 166 days.

TABLE 15.—CHARACTERISTICS OF THE MONTHLY RATE OF EVAPORATION IN INCHES FROM WRIGHT EVAPORIMETER AND CONVERTED IN LIVINGSTON UNITS, SAINTE-ANNE-DE-LA-POCATIÈRE, 1938-1947

Month	Mean	Range	Standard deviation
April	2.04	1.46 - 2.91	0.50
May	6.02	4.14 - 7.92	1.15
June	6 65	4.94 - 9.22	1.29
July	7.10	6.25 - 8.09	0.69
August	6.32	4.66 - 8.15	1.28
September	5.11	4.03 - 7.22	1.11
October	2.20	1.32 - 2.96	0.48
Total	35.24	30.90 - 40.59	3.00

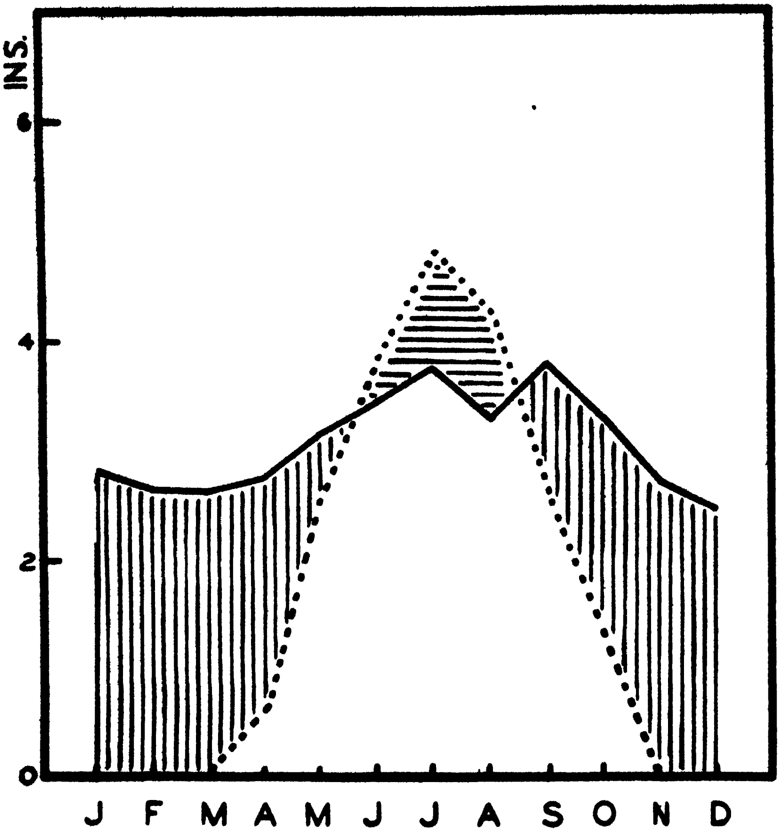

FIGURE 6. March of precipitation (*solid line*) and potential evapotranspiration (*dotted line*) at Sainte-Anne-de-la-Pocatière.

SUNSHINE

Sunshine records in Table 14 show that July has the most hours of sunshine and December the least. Year-to-year variation is the greatest for the month of May and the smallest for the month of December. The average number of hours of sunshine for the year is 1816.6 with a standard deviation of 134.7 hours. This represents 40.8 per cent of possible sunshine. The percentage of possible sunshine is about 32.0 during the winter months and rises to a value of 49.5 for the summer months.

EVAPORATION

The rate of evaporation, as measured by the Wright evaporimeter and reduced to Livingston units, is given in Table 15, from about April 15 to October 15. The length of records covers only a few years. The highest rate of evaporation occurs in July with a low standard deviation.

Thornthwaite (10) has recently discussed an important climatic element called "evapotranspiration" which is the combined evaporation from the soil surface and transpiration from plants. "Potential evapotranspiration" is the amount of water which would transpire and evaporate if it were available. The computation of the "potential evapotranspira-

TABLE 16.—CHARACTERISTICS OF THE HOURLY WIND VELOCITY, SAINTE-ANNE-DE-LA-POCATIÈRE, 1936-1947

Month	Mean	Range	Standard deviation
January	7.4	3 - 13	2.9
February	6.0	4 - 12	2.3
March	5.9	3 - 11	2.3
April	5.5	2 - 9	1.9
May	5 3	3 - 8	1.5
June	4.5	2 - 7	1.5
July	4 5	2 - 6	1.5
August	3.9	3 - 6	0.9
September	4 2	2 - 7	1.8
October	5.9	3 - 9	2.4
November	4 9	2 - 8	2.0
December	6 2	3 - 9	1.8
Year	5 3	3 - 7	1.3

TABLE 17.—PER CENT FREQUENCY OF WINDS FROM EIGHT DIRECTIONS FOR THE VARIOUS MONTHS OF THE YEAR, SAINTE-ANNE-DE-LA-POCATIÈRE, 1918-1947

Month	Percentage of winds from:							
	N.	S.	E.	W.	NE.	NW.	SE.	SW.
January	5	7	14	37	10	9	4	14
February	4	5	16	37	13	8	3	14
March	6	5	12	33	17	8	3	16
April	9	4	14	25	24	8	2	14
May	9	2	14	30	24	7	2	12
June	6	3	12	34	19	9	1	16
July	6	3	8	41	12	11	1	18
August	5	4	8	45	12	11	1	14
September	8	5	13	35	12	9	1	17
October	7	3	9	33	15	12	3	18
November	6	5	13	36	17	8	3	12
December	6	6	11	35	13	10	3	16
Year	7	4	12	35	16	9	2	15

tion" has been made possible by a formula developed by Thornthwaite (10), when the mean monthly value of temperature is available, and the latitude of the station is known. The monthly value of "potential evapotranspiration" was computed for the present station and is graphically shown in Figure 6 in comparison with the precipitation. The annual "potential evapotranspiration" is 19.7 inches. It rises to a maximum of 4.8 inches in July. During the summer months the water deficiency is about 2.4 inches on the average. The climate is dry during these months, because water need is greater than precipitation. However, water stored in soils may decrease to some extent the dryness of this period when rainfall is deficient. The climate is wet the rest of the year, with a water surplus of 16.9 inches which either runs off or is being stored in the soil.

Precipitation alone does not always give an exact picture of the climate in relation to plant need. Examination of rainfall data in Figure 6 indicates that April is relatively dry and July relatively moist. But when precipitation is compared with the "potential evapotranspiration," April becomes wet and July dry.

WIND

Wind velocity is observed twice daily, 8.00 a.m., and 6.00 p.m. The present observations were converted from the Beaufort scale into miles per hour.

Hourly wind velocity is given in Table 16 for the period 1936-47. The region is characterized by constant winds. There are very few calm days. The wind velocity is especially high during the winter months. Winds from the west are dominant for every month of the year. The frequency distribution of the wind direction is shown in Table 17.

SUMMARY

Thirty-five years of weather observations have been computed at Sainte-Anne-de-la-Pocatière. The data were analysed by means of the standard deviation. Precipitation, temperature, length of frost-free period, sunshine, evaporation and wind are recorded and discussed.

ACKNOWLEDGMENTS

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SOME FACTORS AFFECTING APPLE YIELDS IN THE OKANAGAN VALLEY

V. AVAILABLE P, K AND Ca IN THE SOIL[1]

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This paper is the fifth in a series reporting the findings of an investigation started in 1937 into the effects of certain factors on apple tree performance in the Okanagan Valley in British Columbia. In this investigation, two major approaches have been used in studying the nutrient status of the soil. The first has been soil analysis, and the second tissue analysis. In this paper, an initial report is made on the P, K and Ca status of the soil as determined by soil analysis only. The results obtained from tissue analysis will be discussed in a subsequent paper.

Three phases of the soil analysis work will be presented, as follows: *first*, analyses of soil samples from apple fertilizer plots; *second*, soil analyses from areas of known P and K deficiencies; and *third*, correlations between soil analyses and apple tree performance. Each of these will be discussed in turn.

PROCEDURE

Sampling the Soil

The procedure used in sampling the soil has already been described (9). Briefly, the method used was to take 10 samples from around an individual tree at each of three depths (0-8 inches, 8-24 inches, and 24-60 inches), and to composite the samples from each depth. In many cases, a mixture of coarse sand and gravel was encountered before a depth of 60 inches was reached; and in such cases sampling was discontinued at or near the top of the gravel. All samples were taken at distances of 4 to 10 feet from the trunk of the tree. In subsequent work (10), it was found that selecting soil samples from near the trunk of the tree in this manner does not provide a true picture of the nutrient status of the whole soil area. In spite of this, the information gained in this investigation has proved of considerable value.

In the laboratory, the soil samples were allowed to air dry in open cans. They were then screened through a 3 mm. sieve, and the gravel and stones were discarded. Each sample was thoroughly mixed, and stored in covered No. 10 tin cans.

Extracting the Soil

The method used for extracting the soil samples was a modification of the CO_2 extraction procedure developed by McGeorge and his co-workers in Arizona (3, 4, 5). Their final procedure (4) was to add 250 ml. of distilled water to 50 gm. of soil, pass CO_2 through the mixture with occasional shaking for 15 minutes, and filter. The method used in this investigation was as follows:

(*a*) Mix soil and distilled water in the ratio of 1 : 2. The reason for using this ratio was that in the Okanagan Valley the water added to the soil annually by precipitation and irrigation is approximately twice the

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weight of the soil in the 18-inch area (6 to 24 inch depth) of greatest tree root concentration. With most of the samples, the amounts used were 800 gm. of soil and 1600 ml. of water, but with the samples from areas of known deficiencies the amounts used were 100 gm. of soil and 200 ml. of water.

(*b*) Pass CO_2 through the mixture in a steady stream for one hour, with occasional shaking. Let stand over-night under an atmosphere of CO_2.

(*c*) Shake again and filter. The larger samples were filtered by suction through Livingston baked clay atmometers, the smaller ones without suction through Whatman No. 5 filter paper.

P Determination

A modification of the usual Deniges molybdate method (2, 7) was used for determining P. Briefly, the procedure was as follows: Place 15 ml. of soil extract in a test tube. Add 2-6 dinitrophenol indicator and adjust the pH to a faint yellow and then barely to a bright yellow. Make up to 20 ml. with distilled water. Add 1 ml. of 15 per cent sodium bisulphite ($Na\ HSO_3$) solution, mix by inversion, and let stand over-night. Place in a bath of running tap water for 15 minutes. Add 1 ml. of ammonium molybdate solution, made by dissolving 10 gm. of ammonium molybdate in 200 ml. of water and adding this to 600 ml. of 25 per cent sulphuric acid. Mix by inversion. Add 1 ml. of aminonaphtholsulfonic acid solution, made by dissolving 0.5 gm. of 1-2-4 aminonaphtholsulfonic acid powder in a mixture of 400 ml. of 15 per cent sodium bisulphite and 30 ml. of 20 per cent sodium sulphite (2). Mix by inversion and replace in water bath. In 5 hours, take a colorimeter reading using a red filter. A Klett-Summerson colorimeter was used. Results were expressed as parts of P per million parts of dry weight of soil.

Standards containing known amounts of P were run at the same time and in the same manner as the unknowns. Colorimeter readings charted against P contents gave straight-line trends. It was therefore necessary to run standards containing only two concentrations of P.

This procedure was slow, but required only a small amount of operating time and gave good accuracy. All determinations were made in duplicate. By using $Na\ HSO_3$ as a reducing agent, no difficulty was encountered from arsenate, ferric, or nitrate ions. Adjustment to a constant pH was found to be necessary for accuracy. The method used gave a deep blue coloration when the colorimeter reading was taken. A constant temperature was also found to be necessary for accuracy. Somewhat greater accuracy was obtained by keeping the mixtures at tap water temperatures (20 to 25° C.) for 5 hours than by keeping them on a steam bath for ½ or 1 hour.

K Determination

A modification of the usual sodium cobaltinitrite procedure, as adapted to turbidimetric use (1, 6), was developed. The procedure was as follows: Place 2 ml. of the soil extract in a test tube. With soils very low in K, more than this amount is used, and with soils very high in K, less than 2 ml. is used. Add 1 ml. of 40 per cent formaldehyde. Make up

to 5 ml. with distilled water. Place in bath of running water, at a temperature of not over 20° C. Also place in the bath a test tube containing 10 ml. of 95 per cent ethyl alcohol and another containing 5 ml. of sodium cobaltinitrite reagent. (This latter is made by dissolving 100 gm. of sodium cobaltinitrite, 400 gm. of sodium nitrite, and 400 gm. of hydrated sodium acetate in water and making up to 2000 ml.). Test tubes of 1 inch diameter are preferable to smaller tubes for this purpose. After at least 10 minutes of cooling in the bath, pour the mixture containing the unknown quickly and steadily into the sodium cobaltinitrite reagent. Pour back and forth twice, add the alcohol, insert stopper and shake. Return to water bath for 10 minutes and take a colorimeter reading, using a red filter. Results are expressed as parts of K per million parts of dry weight of soil.

Standards containing known amounts of K were run at the same time and in the same manner as the unknowns. Colorimeter readings charted against K contents gave a curved line, and it was therefore necessary to run a whole series of standards with each lot of unknowns.

This method was quite rapid, but was not quite as accurate as desired. The chief cause of variability was found to be in the mixing. By adopting a standard method of mixing and adhering strictly to it, much greater accuracy was attained. Even then, duplicates did not always agree within 10 per cent. When this occurred, further determinations were made until agreement was within 10 per cent. The sodium cobaltinitrite reagent gave just as satisfactory results when it contained sodium acetate as when it contained acetic acid, and there was no difficulty from acetic acid fumes. Because of the high buffering capacity of the reagents, it was not found necessary to make pH adjustments. A constant temperature at or below 20° C., however, was found to be essential for best results. The formaldehyde served to eliminate the effects of the ammonium ion. The alcohol served to bring about rapid formation of turbidity. The turbidity developed was not constant, so that it was necessary to take colorimeter readings at a constant time after adding the reagents.

Ca Determination

A modification of the Peech and English (6) method was used. The modifications were, briefly, as follows: (*a*) The CO_2 extract was used for analysis, as with P and K. (*b*) Bromphenol blue indicator was used to bring all unknowns to a pH of approximately 4.8 before the reagents were added. (*c*) Unknown solutions and reagents were kept at a constant temperature in running tap water. Results were expressed as parts of Ca per million parts of dry weight of soil.

For the most part, this method gave excellent results. All tests were run in duplicate. Where duplicates differed from one another by more than 10 per cent (which seldom occurred), further determinations were made.

Free Lime Determination

The method has already been described (9). It consists of adding hydrochloric acid to a soil-and-water mixture in a 100-ml. graduated cylinder and noting the height of rise of the bubbles. Results are only approximate.

Method of Expressing Results

All results obtained were corrected for percentage of gravel, on the assumption that the nutrient content of the gravel was zero. For example, if the original soil contained 50 per cent of gravel that was discarded on screening, and the screened soil contained 2.0 p.p.m. P, then the corrected figure for P would be 1.0 p.p.m. All nutrient contents were expressed in parts per million of the dry weight of the soil.

In addition to the concentration of each nutrient at each depth in the soil, it was desired to express in some manner the total quantity present in the profile as a whole. This was done in terms of pounds per acre of P, K and Ca, respectively. In transferring parts per million to pounds per acre, it was assumed that an acre foot of soil weighs 4,000,000 pounds. When both surface soils and subsoils were included, this figure was not far from the average for the types of soil encountered in this investigation. The depth of sampling in each case was assumed to be the depth of the profile, that is, to a depth of five feet unless the underlying horizon of stones and coarse sand was encountered above that depth.

FERTILIZER PLOTS

A large number of fertilizer tests have been run with apple trees in the Okanagan Valley. Although by 1940 some of these tests had been conducted for periods of ten years or more, no beneficial effects of P or K had yet been observed. Two of these series of plots are still under test, and still show no measurable beneficial effects of P or K fertilizers (11). Soil samples were collected from three series of the plots in the spring of 1940, and were analysed for P, K, Ca and free lime. These three series included the fertilizer plots started in the Barnard orchard in Penticton in 1930, the plots started in the Butler orchard in East Kelowna in 1928, and the plots started in the Willis orchard in Rutland in 1932. Some of the results have already been published (11); however, they are presented again in Table 1. The data in this table serve as a basis for comparison with data obtained from soils from other parts of the Okanagan Valley, which will be presented below.

It is of interest to note that both the P content and K content tended to decrease with depth. The same was true with the Ca content where no free lime was present. Where free lime was present in the subsoil, however, the Ca content was much higher there than in the surface soil. It will be noted that the P and K contents of the surface 8 inches of Plot P1 were lower than in Plots P2 to P4, while the reverse was true with Ca. The reason for this was that the original surface soil had mostly been scraped off Plot P1 in levelling operations before planting.

The most important data in Table 1 are the contents of P and K in the untreated and N-only plots. With P, the lowest content in the surface 8 inches was 0.8 p.p.m. in Plots P1 and B30. With K, the lowest content in the surface 8 inches was 64 p.p.m. in Plot B30. It can safely be assumed, then, that by the methods of analysis used these quantities are above the deficiency ranges. It is of interest also to note that the lowest content of Ca in the surface 8 inches was 74 p.p.m. in Plot B30.

TABLE 1.—P, K AND CA CONTENTS OF FERTILIZER PLOT SOILS

Plot No.	Treatment	Soil depth	pH	P content	K content	Ca content	Free lime
		in.		p.p.m.	p.p.m.	p.p.m.	%
Barnard Plots							
P1	O*	0-8	7.61	0.8	69	485	1.4
		8-24	8.19	0.2	48	559	5.2
		24-60	8.29	0.2	49	469	2.8
P2	N	0-8	6.85	3.3	105	187	0.0
		8-24	7.88	1.2	57	455	2.1
		24-60	8.08	0.4	51	484	5.2
P3	NP	0-8	6.28	11.9	81	183	0.0
		8-24	7.47	1.1	51	447	0.1
		24-60	8.13	0.6	46	565	3.9
P4	NPK	0-8	6.36	10.2	132	145	0.0
		8-24	7.75	1.2	56	542	0.6
		24-60	8 13	0.3	52	590	5.4
Butler Plots							
K11	NP	0-8	6.46	10.1	79	157	0.0
		8-24	6.36	0.5	20	27	0.0
K12	NPK1	0-8	5.87	8.8	105	82	0.0
		8-24	6.34	0.5	20	24	0.0
K13	NPK2	0-8	6.30	8.2	110	106	0.0
		8-24	6.34	1.1	33	25	0.0
K14	NPK3	0-8	5.99	8.9	180	88	0.0
		8-24	6.36	0.8	26	33	0.0
K15	O	0-8	6.66	2.0	74	98	0.0
		8-24	6.46	0.2	19	20	0.0
K46	N	0-8	6.27	1.6	80	94	0.0
		8-24	6.51	0.2	14	20	0.0
K51	NP	0-8	5.67	8.4	80	96	0.0
		8-24	6.15	0.5	25	21	0.0
Willis Plots							
B29	O	0-8	6.93	1.4	68	106	0.0
		8-30	7.10	0.3	35	51	0.0
B30	N	0-8	6.21	0.8	64	74	0.0
		8-27	6.68	0.3	33	59	0.0
B31	NP	0-8	5.82	16.4	87	111	0.0
		8-27	6.78	2.6	36	80	0.0

* O—no treatment; N—nitrogen; P—phosphate; K—potash.

SOILS WITH PROVEN P AND K DEFICIENCIES

As already stated, no cases of proven P or K deficiencies have yet been encountered with tree fruits in the southern interior of British Columbia. This has made it very difficult to set up any standards of sufficiency or deficiency. Information of some value has been obtained from the fertilizer plots, but it has been impossible from this alone to determine the range of values for either element that can be considered as falling at the "critical"

points, between sufficiency and deficiency. In order to gain this information, soil samples with proven P or K deficiencies were obtained in 1943 from other tree fruit areas. The sources from which these samples were obtained are listed in Tables 2 and 3. Also shown in these tables are the depths of sampling, the crop concerned, and the sufficiency or deficiency of P or K for this crop. Where the depth is not stated, it can be assumed that it was approximately 0 to 6 inches.

These soil samples were extracted and analysed by the same procedures as used on the Okanagan Valley samples. The pH and the P and K contents are summarized in Tables 2 and 3.

No one specified content of "available" P or K in the soil can be accepted as representing the dividing line between sufficiency and deficiency, i.e. the "critical point". The position of this critical point is affected by a number of other factors, such as the following: (*a*) the depth of the soil, (*b*) the type of crop, (*c*) the soil moisture content, (*d*) the presence of other limiting factors. Instead of a "critical point," therefore, the best that can be anticipated by any method of analysis is a "doubtful range". This is especially true where only the surface soil is being analysed. In a previous paper (10), the author has shown the importance of the subsoil as well.

Some overlapping of "sufficiency" and "deficiency" can be found in Tables 2 and 3. Prunes in California did not respond to P fertilizer with only 0.14 p.p.m. P in the soil, while vegetables in Washington responded with as high as 0.88 p.p.m. P in the soil. Tree fruits in Ontario showed no need for K fertilizer with only 33 p.p.m. K present in the soil, while tree fruits in Pennsylvania responded to K fertilizer with 44 p.p.m. K present. On the whole, however, the results were reasonably consistent. All responses obtained with P fertilizer on tree fruits were with 0.23 p.p.m. or less of P in the soil; and all responses obtained with K fertilizer were with 44 p.p.m. or less of K present.

TABLE 2.—DATA ON SOILS FROM AREAS DEFICIENT IN P

Sample No.	Source*	Crop concerned	pH	P content
				p.p.m.
U1	Aitken clay loam, Ore.	Not stated	5 38	0.13
U2	Aitken silty clay loam, Ore.	Not stated	5.31	0.09
U3	Melbourne silty clay loam, Ore.	Not stated	5.29	0 16
U5	Salkum clay loam, Ore.	Not stated	4.58	0.09
U6	Prosser, Wash.	Vegetables	6 92	0 88
U7	Prosser, Wash.	Vegetables	6.20	2.70**
U8	Prosser, Wash.	Vegetables	6.14	0.40
U10	Aitken clay loam, Calif.	Annuals but not prunes	5.98	0.14
U11	Norfolk sandy loam, Miss.	Tree fruits	5.07	0.05
U13	Ontario	Tree fruits	6.17	0.23
U14	Ontario	Tree fruits	6.29	0.21
U15	Ontario	Tree fruits	5.26	0.05
U16	Ontario	Tree fruits	5.57	0.16
U17	Ontario	Tree fruits	6.41	2.20**
U18	Ontario	Tree fruits	6.47	2.05**
U21	Quebec	Vegetables	5.21	0.27
U23	Merville loam, B.C.	General	5.30	0.05
U24	Keating sandy loam, B.C.	General	5.23	0.72**

* As far as known, all of these samples were obtained at a depth of 0 to 6 inches.
** P not deficient in these cases. P was reported to be deficient in all samples not thus marked.

TABLE 3.—DATA ON SOILS FROM AREAS DEFICIENT IN K

Sample No.	Source	Crop concerned	Depth*	pH	K content
			in.		p.p.m.
U4	Polk clay loam, Ore.			5.11	7
U9	Pinole soil series, Calif.	Tree fruits	0-12	5.59	8
U13	Ontario	Tree fruits		6.17	9
U14	Ontario	Tree fruits		6.29	15
U15	Ontario	Tree fruits		5.26	8
U16	Ontario	Tree fruits		5.57	8
U17	Ontario	Tree fruits		6.41	13
U18	Ontario	Tree fruits		6.47	33**
U19	Ontario	Tree fruits		5.95	28
U20	Ontario	Tree fruits		7.19	7
U25a	Massachusetts	Tree fruits	0-2	4.78	85**
U25b			2-8	4.77	40
U25c			8-20	5.10	31
U26a	Massachusetts	Tree fruits	0-8	5.91	5
U26b			8-20	5.37	3
U27a	Massachusetts	Tree fruits	0-8	4.68	34**
U27b			8-20	4.93	28
U28a	Massachusetts	Tree fruits	0-8	4.37	9
U28b			8-20	4.91	8
U31	Sassafras gravelly loam, Md.	Tree fruits	0-10	5.84	5
U32	Bath gravelly silt loam, N.Y.	Vegetables		5.06	4
U35	New York	Tree fruits	0-8	5.92	7
U36	New York	Tree fruits	0-8	5.01	68**
U37	New York	Tree fruits	0-8	5.50	208**
U38	Ashe-Porters series, Pa.	Tree fruits		6.17	26
U39	Penn-Porters mixture, Pa.	Tree fruits		6.39	10
U40	Chester-Manor series, Pa.	Tree fruits		5.01	44
U41a	Florida	Tung	0-6	5.23	10
U41b			6-12	5.11	4
U43a	Florida	Tung	0-6	5.37	8
U43b			6-12	5.16	4

* Where the depth is not stated, it is assumed that it is approximately 0-6 inches.
** K not deficient in these cases. K was reported to be deficient in all soils not thus marked.

The question arises as to whether the values of 0.23 p.p.m. P and 44 p.p.m. K can be accepted as "critical values". In other words, should fertilizers be recommended wherever the surface soil contains less than these values, but not where it contains more? This would not be safe for general application even to just tree fruits. It is quite possible that under certain conditions responses to P or K fertilizer could be obtained with even higher amounts than these present in the soil. In spite of the fact that in some cases no response has been obtained with less than 0.23 p.p.m. P or 44 p.p.m. K present in the soil, it appears safer to set tentative critical values at higher points than these. The values in use at present in this laboratory are 0.40 p.p.m. P and 50 p.p.m. K in the surface soil. It is assumed that when the soil is getting this low in P or K it is good insurance to apply the required fertilizer in order to prevent P or K deficiency. These figures refer of course to only the surface soil. Where cumulative quantities can be determined for the whole profile, it appears preferable to base the critical values on these rather than on the amounts in the surface soil only.

It is of interest to compare these critical values with the P and K contents in the fertilizer plots. The lowest values obtained in the surface soil of the fertilizer plots were 0.80 p.p.m. P and 64 p.p.m. K.

SOIL ANALYSES FROM McINTOSH PLOTS

In 1937, 73 plots of McIntosh trees were established in the Okanagan Valley, mostly in grower-owned orchards. The fertilizer plots already described in this paper were included. Records of yield and vigour were taken for a period of six years, and soil samples were collected in 1940. The methods of plot selection and recording, and the tree records obtained, have been outlined in the first paper (8) of this series; while the methods of soil sampling and some of the soils data obtained have been presented in the second paper (9) of the series.

Some of the plots received P fertilizer; some K fertilizer; some both; some neither. A careful examination was made of the 400 trees in the plots, but no leaf symptoms of P, K or Ca deficiency were observed. It has therefore been assumed that any deficiencies of these three elements which might have occurred in these plots could be of a minor nature only.

The P, K and Ca analyses of the soils from these plots are summarized in Table 4 in the Appendix. As added information on these soils, there are also included in this table the moisture-holding capacity per foot of soil, the pH, and the content of free lime.

Effects of Soil Depth

The data in Table 4 reveal an effect of soil depth similar to that noted in the special fertilizer plots. Where no P fertilizer had been applied, the P content in the 8-24 inch depth was one-third or less of that in the 0-8 inch depth. Usually the P content below 24 inches was somewhat less than at 8-24 inches. Where P fertilizers had been applied, the discrepancy was much greater between the 0-8 inch depth and the 8-24 inch depth. It appeared that very little of the P applied as fertilizer had moved down below the 8 inch level. With K the effects of depth were somewhat similar, except that the differences between the 0-8 inch depth and the 8-24 inch depth were not so marked.

With Ca, the effects of depth of soil depended primarily on the texture and on the depth of the profile. With sandy, shallow soils, the Ca content lessened with depth, in a manner similar to P and K. With deep, heavy soils, however, the reverse held true; that is, the Ca content in the subsoil was usually much higher than in the surface soil. This was due primarily to the presence of free lime in the lower horizons of the deep silts and clays. The depth at which the lime was encountered was usually about 15 to 20 inches, though some exceptions occurred. Where surface soil had been removed by erosion or by levelling operations (e.g. Plot P1), lime was found at or close to the surface. In deep sandy loams, on the other hand, the lime did not appear above a depth of 30 inches. In all cases, once lime was encountered it continued to the full depth of examination, which was usually 60 inches with the silt and clay soils. As noted in a previous paper (9), the high lime and high Ca contents in these soils were not associated with a hardpan condition.

Effects of Soil Texture

In the surface soil, the effects of texture were masked to some extent by fertilizer treatments. This was especially true with P and K. Indications are that the effects of fertilizing were negligible below a depth of 8 inches.

Evidence of the effects of soil texture has been obtained by correlating each element with various measurements of texture. Some of the correlations obtained with P were as follows:

(*a*) *In 0-8 inch samples*

Between p.p.m. P and per cent clay	−0.060
Between p.p.m. P and per cent colloid	−0.045
Between p.p.m. P and moisture-holding capacity	+0.011

(*b*) *In 8-24 inch samples*

Between p.p.m. P and per cent clay	−0.081
Between p.p.m. P and per cent colloid	+0.090
Between p.p.m. P and moisture-holding capacity	+0.275*

Owing to the small number of samples from below 24 inches, correlations were not calculated on them.

In the above correlations and in those to follow, the degree of significance is indicated along with the coefficient of correlation. Two asterisks mean that the coefficient is "highly significant," with odds greater than 99 : 1. One asterisk means that it is "significant," with odds between 19 : 1 and 99 : 1. Lack of an asterisk means that it is "non-significant," with odds less than 19 : 1.

The last correlation of the six is significant, but all the others are non-significant. There is no good evidence here of any effect of soil texture on the P content of the soil. If such a relationship existed, it was effectively masked by other factors.

Results with K were as follows:

(*a*) *In 0-8 inch samples*

Between p.p.m. K and per cent clay	+0.114
Between p.p.m. K and per cent colloid	+0.161
Between p.p.m. K and moisture-holding capacity	+0.286*

(*b*) *In 8-24 inch samples*

Between p.p.m. K and per cent clay	+0.073
Between p.p.m. K and per cent colloid	+0.187
Between p.p.m. K and moisture-holding capacity	+0.558**

The last correlation is highly significant, the third one significant. All six correlations are positive. It can therefore be considered that some evidence has been found to indicate a relationship between soil texture and K content. In other words, there was some tendency for an increased content of K as the soil became heavier in texture.

Results with Ca were as follows:

(*a*) *In 0-8 inch samples*

Between p.p.m. Ca and per cent clay	+0.328**
Between p.p.m. Ca and per cent colloid	+0.426**
Between p.p.m. Ca and moisture holding capacity	+0.642**

(*b*) *In 8-24 inch samples*

Between p.p.m. Ca and per cent clay	+0.437**
Between p.p.m. Ca and per cent colloid	+0.544**
Between p.p.m. Ca and moisture holding capacity	+0.738**

These results give evidence of a very close relationship between Ca and soil texture; that is, the heavier the soil, the higher the content of available Ca.

With all three elements (P, K, Ca), the total amount of each that was present in available form depended not only on soil texture but on soil depth. The heavier soils were, on the average, deeper than the lighter soils. Thus the total amounts of available K and Ca per profile were much greater with the deep soils than with the shallow soils. Even with P, where little relationship was found between the concentration of the element and the texture of the soil, somewhat more total available P was present in deep soils than in shallow soils. Correlations were calculated between the total amount of each element in pounds per acre and the total moisture-holding capacity in inches of water per profile, with results as follows:

Between pounds P and moisture capacity..................	+0.152
Between pounds K and moisture capacity..................	+0.878**
Between pounds Ca and moisture capacity..................	+0.857**

These last two correlations are highly significant, the first is non-significant. Thus when soil texture and soil depth were both taken into consideration, they were found to exert a marked effect on the K and Ca contents, and a minor effect on the P content.

Relation to Soil pH

Correlations obtained with soil pH were as follows:

Between p.p.m. P and pH (0-8)..........................	−0.204*
Between p.p.m. P and pH (8-24)..........................	−0.209*
Between p.p.m. K and pH (0-8)..........................	+0.128
Between p.p.m. K and pH (8-24)..........................	+0.341**
Between p.p.m. Ca and pH (0-8)..........................	+0.527**
Between p.p.m. Ca and pH (8-24)..........................	+0.833**
Between p.p.m. Ca and per cent lime (8-24)..................	+0.640**

The evidence from these correlations indicates a definite tendency for a higher pH to be accompanied by a lower content of available P. This is no doubt due to a lower solubility of P with free lime present. The pH was not low enough in any samples to cause any marked fixation of P with Fe or Al.

There was a distinct tendency for K to increase as the pH increased. Whether this was due to a direct relationship between pH and K content is not known. It was more probably due to the fact that those soils with a higher pH were for the most part those with a heavier texture. As already noted, there was a tendency toward higher K contents in heavier soils.

As would be expected, there was a very close relationship between the Ca content and the pH; in other words, the higher the Ca content, the higher the pH. This appeared to be due primarily to the effects of lime on both Ca content and pH. Even where no free lime was recorded, however, this relationship between Ca and pH was still found to hold true.

Relation to Tree Vigour

To determine the relation between nutrient content of the soil and tree vigour, the total amount of each element present in available form in the profile, expressed as pounds per acre, was correlated with the terminal lengths of the trees over a six-year period (8). The results of these correlations were as follows:

Between pounds P per acre and terminal length............	+0.134
Between pounds K per acre and terminal length............	+0.378**
Between pounds Ca per acre and terminal length............	+0.275*

It is evident from these data that greater supplies of K and Ca in the soil were accompanied by greater vigour in the trees. The same trend was evident with P, but to a lesser degree. It does not necessarily follow, however, that each of these elements was directly instrumental in increasing tree vigour. As noted in a previous paper (8), tree vigour tended to be greater in the deeper and heavier soils than in the lighter and shallower soils. Both K and Ca contents were also much greater in the deeper and heavier soils. It is thus possible that the greater vigour obtained on deeper and heavier soils might have been due to factors other than P, K or Ca.

As already noted, soil texture and soil depth can be represented adequately in combined form by the total moisture-holding capacity in the profile. When the above three correlations were re-calculated, with the effects of total moisture-holding capacity per profile eliminated, the results were + 0.103, + 0.321**, and + 0.092, respectively. The second of these correlations is highly significant, the other two non-significant. There thus remains a distinct possibility that the degree of vigour has been affected in some manner by the K content of the soil. In view of the free interaction of the many factors concerned, this possibility can be accepted as a possibility only.

Relation to Tree Yield

To determine the relation between nutrient content of the soil and tree yield, the total amount of each element present in available form in the profile, expressed as pounds per acre, was correlated with both average yield per tree and average yield of "profitable" fruit per tree over a six-year period (8). The "profitable" fruit included those fruits of Fancy or Extra Fancy grade that were within the diameter range of 2¼ to 3⅛ inches. The results of these correlations were as follows:

Between pounds P per acre and total yield................	+0.152
Between pounds P per acre and profitable yield............	+0.070
Between pounds K per acre and total yield................	+0.374**
Between pounds K per acre and profitable yield............	+0.356**
Between pounds Ca per acre and total yield................	+0.372**
Between pounds Ca per acre and profitable yield............	+0.462**

The first two of these correlations are non-significant, the last four highly significant. There was thus a distinct tendency for higher yields to occur where the K and Ca contents of the soil were higher. As with tree vigour, however, it does not necessarily follow that the higher yields were caused by the higher K and Ca. Highly significant correlations have already been reported (8) between the total moisture-holding capacity of

the profile and tree yields. Elimination of the effects of moisture-holding capacity from the correlations involving total yield produced the following adjusted correlations:

Between pounds P per acre and total yield................	+0.095
Between pounds K per acre and total yield..	+0.032
Between pounds Ca per acre and total yield.....	+0 045

These correlations are all non-significant and indeed very low. In other words, when the combined effects of soil texture and soil depth have been removed, no evidence of a relationship remains. There is therefore no proof of any effect of P, K or Ca on the yield. However, this cannot be accepted as final proof that actually there is no such effect. The possibility must be borne in mind that the effects of combined soil texture and soil depth on yield may be due in part to the effects of K or Ca. Evidence to date indicates, however, that the effects of soil texture and depth are due more to other factors—such as moisture content of soil, root distribution, N content, and humus content—than to P, K and Ca contents.

P and K Status

The correlation method has provided no proof of deficiencies of P or K in Okanagan soils. The question is, how do the P and K analyses on the soil samples from the 73 McIntosh plots compare with those from the fertilizer plots and from the areas of known P and K deficiencies?

From the evidence already presented (11), it can be assumed that P and K were present in sufficient amount in all of those plots of the fertilizer series that received no P or K fertilizer. The plots more especially concerned were P1, P2, K15, K46, B29 and B30. In these plots, the lowest P content in the 0-8 inch layer was 0.8 p.p.m. in Plots P1 and B30, and the lowest total P in the profile was 4 pounds per acre in Plot B30. An examination of Table 4 reveals that of the 73 plots, four showed less than 0.8 p.p.m. P in the 0-8 inch layer of soil, and seven showed less than 4 pounds P per acre in the profile. There is thus a distinct possibility that the P content might be deficient in some areas or in some soil types where field tests with fertilizers have not yet been conducted.

In those plots of the fertilizer series that received no K fertilizer, the lowest K content in the 0-8 inch layer was 64 p.p.m. in Plot B30, and the lowest total K in the profile was 292 pounds per acre in Plot K15. Of the 73 McIntosh plots, ten showed less than 64 p.p.m. K in the 0-8 inch layer, and seven showed less than 292 pounds per acre in the profile. Most of the figures were not far below 64 p.p.m. and 292 pounds, respectively. The possibility must be admitted, however, that K deficiency might exist in some Okanagan Valley soils.

The highest contents of P and K determined on surface soil samples from orchards with known P and K deficiency were 0.23 p.p.m. and 4 p.p.m., respectively. In the McIntosh plots, there were none with surface soil containing less than 0.23 p.p.m. P, and only one with surface soil containing less than 44 p.p.m. K. If 0.40 p.p.m. P and 50 p.p.m. K are to be accepted as critical values (as suggested above), then one plot can be considered as possibly deficient in P and two plots as possibly deficient in K. Once again, the evidence indicates the possibility that deficiencies of P and K have occurred in Okanagan Valley soils, but there is little if any definite proof that such is the case.

GENERAL CONCLUSIONS

No definite proof has been obtained of deficiencies of P or K in Okanagan Valley orchard soils. Some evidence has been presented, however, indicating that such deficiencies might actually have developed in some of the soil types studied. No definite relationships were found between P, K or Ca content of the soil and tree yield; nor was any response obtained from P or K fertilizers in a number of plots. However, the P and K contents in some orchard soils were found to be lower than the lowest contents in the check plots of the fertilizer plot series. They also came close, in some cases, to the P and K contents of soil samples from areas in Canada and the United States of known P or K deficiency. For the most part, the lowest P and K contents were found either in shallow, sandy soils or in orchards where the original surface soil had been lost by erosion or by levelling operations.

The evidence thus far obtained appears to be sufficient to justify the following fertilizer recommendations:

(1) Apply sufficient nitrogenous fertilizer to mature apple trees to induce an annual terminal growth of 10 to 12 inches (8).

(2) Apply phosphate as well as nitrogen to sandy or shallow soils, or to orchard soils where the original surface soil has been lost (11). The method that has been recommended from this Station for accomplishing this is to apply sufficient 16-20-0 fertilizer to induce 10 to 12 inches of terminal growth on apple trees.

(3) Apply potash, as well as nitrogen and phosphate, to soils that are *both* light and shallow (11). The recommended method is to apply sufficient 8-10-5 fertilizer to induce an annual terminal growth of 10 to 12 inches; or better still, to use 16-20-0 supplemented with some muriate of potash, a combination that is at present much cheaper here than is 8-10-5.

SUMMARY

Studies were made of the available P, K and Ca status of Okanagan Valley orchard soils. Soil samples were collected from fertilizer plots and from 73 grower-operated McIntosh blocks, at depths of 0-8, 8-24 and 24-60 inches. Soil extracts were made with CO_2-saturated water in a soil : water ratio of 1 : 2, and analyses were made for P, K and Ca. Results were expressed in terms of parts per million of dry soil at each depth, and also in terms of pounds per acre for the total depth. Determinations of moisture-holding capacity, pH, lime content, and mechanical analyses were also made.

Samples of orchard soil were obtained from areas in Canada and the United States of known P or K deficiency. These were analysed by the same procedures for P and K.

No measurable response was obtained from fertilizer applications of P and K. In those plots of the fertilizer series not receiving P or K, the lowest P contents were 0.8 p.p.m. in the surface soil and 4 pounds per acre in the profile, and the lowest K contents were 64 p.p.m. in the surface soil and 292 pounds per acre in the profile. Of the 73 McIntosh plots, four showed less than 8 p.p.m. P and ten showed less than 64 p.p.m. K in the surface soil. In the soils from the areas of known P and K deficiency, the

highest values associated with deficiency for tree fruits were 0.23 p.p.m. P and 44 p.p.m. K. Of the 73 plots, none showed less than 0.23 p.p.m. P and only one showed less than 44 p.p.m. K in the surface soil. Only one plot showed less P and only two showed less K than arbitrarily set "critical" values of 0.40 p.p.m. P and 50 p.p.m. K. There was thus good indication of the possibility of P and K deficiencies in some soil types not yet included in the fertilizer tests, but no definite proof that such deficiencies actually existed.

Correlations were calculated between the P, K and Ca contents of the soil on the one hand and tree vigour and yield on the other hand. Both K and Ca showed distinct positive correlations with both vigour and yield; however, when adjustments were made for soil texture and depth, almost all of the correlations lost their significance. There was no definite evidence of any effect of P, K or Ca on tree vigour or yield.

Both the P and K contents were higher in the surface soil than in the subsoil. In sandy soils, Ca was higher in the surface soil; but in heavy soils, Ca and free lime were much higher in the subsoil. There was little correlation between soil texture and P content; however, both K and Ca were present in larger quantity in heavy soils than in sandy soils. The pH showed a negative correlation with the P content, and positive correlations with the K, Ca, and lime contents.

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APPENDIX

TABLE 4.—DATA FROM McINTOSH PLOT SOILS

Plot No.	Soil depth	M.C.F.*	pH	P content		K content		Ca content		Lime content
				At each depth	Profile total	At each depth	Profile total	At each depth	Profile total	
	in.	in.		p.p.m.	pounds	p.p.m.	pounds	p.p.m.	pounds	%
P1	0-8	3.59	7.61	0.8		69		485		1.4
	8-24	3.43	8.19	0.2		48		559		5.2
	24-60	3.10	8.29	0.2	5	49	1028	469	9904	2.8
P2	0-8	3.58	6.85	3.3		105		187		0.0
	8-24	3.48	7.88	1.2		57		455		2.1
	24-60	3.43	8.08	0.4	20	51	1196	484	8736	5.2
P3	0-8	3.63	6.28	11 9		81		183		0.0
	8-24	3.32	7.47	1.1		51		447		0.1
	24-60	3.03	8.13	0.6	45	46	1040	565	9652	3.9
P4	0-8	3.52	6.36	9.7		132		145		0.0
	8-24	3.31	7.75	1.2		56		542		0.6
	24-60	3.43	8.13	0.3	36	52	1276	590	10360	5.4
P5	0-8	3.45	6.67	2.9		132		205		0.0
	8-24	3.28	7 93	0.5		59		498		1.6
	24-60	3 05	8.33	0.4	15	48	1244	613	10552	3.0
P6	0-8	3.37	6.68	5.6		110		193	740	0.0
	8-24	1.98	6 35	0.3	17	25	424	42		0.0
P7	0-8	2 50	6.68	3.2		78		141		0.0
	8-24	2.85	6.73	1.1	14	37	404	64	716	0.0
P9	0-8	3.22	7.13	3 3		119		172		0.0
	8-24	3.32	7 89	0.4		55		383		0.1
	24-60	3 69	8.19	0.3	15	46	1164	488	8360	4.9
P10	0-8	2.96	7 40	4.3		117		164		0.0
	8-24	2.83	7.79	1 2		61		240		0.0
	24-60	3.50	8.14	0.7	26	48	1212	585	8736	4.5
S10	0-8	2.24	6.78	0.6		59		108		0.0
	8-24	1.42	6 64	0.1	2	22	272	38	492	0.0
S12	0-8	3.37	6.68	0.9		62		146	1768	0.0
	8-24	1.98	6.35	0.5	5	32	336	259		0.0
T2	0-8	2.94	6.11	4.0		162		354		0.0
	8-36	2.55	8.06	0.6	17	78	904	473	5360	3.3
T3	0-8	2.53	6.15	3.6		101		263		0.0
	8-24	1.52	7.31	0.3	11	25	404	66	1052	0.0
T6	0-8	2.65	7.64	2.7		98		307		0.0
	8-24	1.77	7.48	0.5	10	29	416	109	1400	0.0
T7	0-8	2.19	7.39	2.2		70		212		0.0
	8-24	1.21	7.28	0.4	8	21	300	87	1028	0.0
T8	0-8	3.10	7.27	6.7		100		295		0.0
	8-30	2.27	7.86	0.8	24	39	556	398	3708	0.6
T9	0-8	2.44	7.22	5.3		83		167		0.0
	8-24	1.86	7.29	0.8	19	36	412	98	968	0.0

* M.C.F.—Moisture holding capacity of the soil, expressed in terms of inches of water per foot of soil.

TABLE 4.—DATA FROM McINTOSH PLOT SOILS—*Continued*

Plot No.	Soil depth	M.C.F.*	pH	P content		K content		Ca content		Lime content
				At each depth	Profile total	At each depth	Profile total	At each depth	Profile total	
	in.	in.		p.p.m.	pounds	p.p.m.	pounds	p.p.m.	pounds	%
K2	0-8	2.87	6.10	1.1		81		130		0.0
	8-20	1.95	6.57	0.2	3	32	344	43	520	0.0
K6	0-8	3.00	6.35	2.0		92		122		0.0
	8-18	1.58	6.77	0.3	6	32	352	28	416	0.0
K7	0-8	2.96	6.27	2.4		79		93		0.0
	8-24	2.85	6.67	0.6		24		66		0.0
	24-44	2.95	7.84	0.9	16	18	460	380	3132	0.5
K8	0-8	3.84	7.02	1.6		87		156		0.0
	8-24	4.00	7.64	0.5		28		420		2.5
	24-60	4.22	7.96	0.2	10	43	896	351	7612	2.2
K9	0-8	3.08	6.06	3.7		92		81		0.0
	8-24	2.75	6.90	0.9		46		81		0.0
	24-35	2.65	8.34	0.9	18	46	656	299	1744	0.9
K10	0-8	2.76	6.73	1.4		48		89		0.0
	8-27	1.16	6.49	0.2	5	5	160	19	356	0.0
K11	0-8	2.89	6.46	10.1		79		157		0.0
	8-22	1.01	6.36	0.5	29	20	312	27	504	0.0
K12	0-8	2.74	5.87	8.8		105		82		0.0
	8-23	1.12	6.34	0.5	26	20	388	24	320	0.0
K13	0-8	2.84	6.30	8.2		90		106		0.0
	8-25	1.26	6.34	1.1	28	33	424	25	424	0.0
K14	0-8	2.78	5.99	8.9		180		88		0.0
	8-24	1.25	6.36	0.8	28	26	620	33	412	0.0
K15	0-8	2.40	6.66	2.0		74		98		0.0
	8-23	1.07	6.46	0.2	6	19	292	20	360	0.0
K16	0-8	3.22	6.70	3.1		114		115		0.0
	8-24	3.20	6.96	0.8		56		142		0.0
	24-54	3.73	7.98	0.6	19	50	1104	381	4876	3.0
K17	0-8	3.50	6.64	3.8		119		113		0 0
	8-24	3 73	6.54	0.8		56		60		0.0
	24-48	4.12	7.80	0.9	22	30	860	485	4500	2.6
K18	0-8	4.18	6.72	1.9		98		169		0.0
	8-24	4.45	7.74	0.3		25		244		2.7
	24-60	4.22	8.23	0.1	9	53	1028	316	4912	3.3
K21	0-8	2.73	6.75	2.8		115		120		0.0
	8-26	2.54	6.74	0.3	10	57	652	60	680	0.0
K22	0-8	2.65	5.83	1.8		70		69		0.0
	8-22	1.60	6.14	0.1	5	19	276	18	268	0.0
K24	0-8	2.78	6.54	2.1		90		101		0.0
	8-24	1.97	6.64	0.2		44		49		0.0
	24-57	2.58	8.02	0.4	11	45	972	317	4016	0.7
K25	0-8	4.08	6.53	1.3		81		132		0.0
	8-24	4.58	7.35	0.5		58		404		1.4
	24-60	4.58	7.78	0.1	7	58	1220	364	6896	2.3

TABLE 4.—DATA FROM McINTOSH PLOT SOILS—*Continued*

Plot No.	Soil depth	M.C.F.*	pH	P content		K content		Ca content		Lime content
				At each depth	Profile total	At each depth	Profile total	At each depth	Profile total	
	in.	in.		p.p.m.	pounds	p.p.m.	pounds	p.p.m.	pounds	%
K27	0-8	3.35	6.61	0.9		92		151		0.0
	8-40	0.95	6.66	0.2	4	17	424	20	616	0.0
K39	0-8	1.23	6.56	0.4		30		57		0.0
	8-29	1.25	6.30	0.1	2	17	200	27	340	0.0
K44	0-8	2.86	5 78	0 8		78		120		0.0
	8-22	0.97	6.10	0.1	2	5	232	25	436	0.0
K46	0-8	2.74	6.27	1 6		80		94		0.0
	8-22	1.29	6.51	0.1	5	18	296	20	344	0.0
K48	0-8	4.26	6 63	1.7		84		177		0.0
	8-24	4.35	7 65	1.2		64		339		1.7
	24-60	4.35	8.22	0 1	13	18	780	224	4968	3.2
K49	0-8	4.32	6 69	0 7		65		154		0 0
	8-24	4.62	7.95	0 1		53		294		3.6
	24-60	4 67	7.63	0 5	8	54	1101	422	7084	2.0
K51	0-8	2.79	5 67	8 4		80		96		0.0
	8-21	1.32	6 15	0 5	24	25	320	29	380	0.0
K53	0-8	2 44	6 04	0 6		57		81		0.0
	8-28	1 09	5 98	0 1	2	30	352	21	356	0.0
K54	0-8	2.86	6 40	0 7		61		83		0.0
	8-25	0 94	6.36	0 1	2	15	248	22	344	0.0
B1	0-8	3 05	6.21	2 2		91		78		0.0
	8-24	2.88	6.69	0 5		46		94		0.0
	24-57	3.23	8 01	0.5	15	43	960	325	3092	0.9
B29	0-8	2.85	6.93	1 4		68		106		0.0
	8-30	2.60	7.10	0 3	6	35	436	51	660	0.0
B30	0–8	2.92	6.21	0.8		64		74		0.0
	8-27	2.68	6.68	0.3	4	33	380	59	568	0.0
B31	0-8	2.92	5 82	16 4		87		111		0.0
	8-27	2.70	6 78	2.6	60	36	460	80	804	0.0
B33	0-8	2.70	6 60	2.2		63		87		0.0
	8-24	2.65	6 44	0 5		36		57		0.0
	24-36	2.38	6.93	0.5	10	36	504	48	728	0.0
B34	0-8	2.58	6.47	3.3		95		124		0.0
	8-24	2.65	6.58	0 9		61		82		0.0
	24-38	1.34	6 65	0.5	16	25	692	22	872	0.0
B36	0-8	3.02	6.02	1.3		59		85		0.0
	8-31	1.67	7.19	0.3	5	23	332	149	1372	0.0
B37	0-8	3.12	6.12	0.8		58		82		0.0
	8-27	1.88	6.62	0.2	3	23	300	71	668	0.0
B38	0-8	2.98	6.56	1.4		63		108		0.0
	8-27	2.60	6.32	0.2	5	31	364	56	644	0.0
G17	0-8	2.06	7.02	1.5		64		156		0.0
	8-24	1.66	7.31	0.5		34		84		0.0
	24-40	2.56	8.21	0.3	8	43	580	393	2960	1.5

TABLE 4.—DATA FROM McINTOSH PLOT SOILS—*Concluded*

Plot No.	Soil depth	M.C.F.*	pH	P content		K content		Ca content		Lime content
				At each depth	Profile total	At each depth	Profile total	At each depth	Profile total	
	in.	in.		p.p.m.	pounds	p.p.m.	pounds	p.p.m.	pounds	%
G18	0-8	2.37	6.36	10.1		98		102		0.0
	8-24	2.03	6.79	1.7		48		60		0.0
	24-44	2.32	7.73	0.4	38	38	768	215	2024	0.1
G19	0-8	4.10	7.12	2.5		122		584		0.0
	8-24	3.67	7.60	0.7		48		724		1.0
	24-57	3.46	8.12	0.2	12	53	1168	494	9040	6.2
G20	0-8	4.08	7.15	1.9		136		715		0.0
	8-24	4.20	7.68	0.3		36		881		2.7
	24-60	4.20	7.92	0.1	7	25	856	774	15640	4.0
G26	0-8	2.92	6.94	2.8		94		95		0.0
	8-24	2.82	8.12	0.8		53		502		0.1
	24-60	2.73	8.23	0.6	19	45	276	428	7780	0.2
G42	0-8	3.27	6.95	1.8		100		121		0.0
	8-24	3.03	6.63	0.3		53		70		0.0
	24-60	2.73	8.18	1.4	23	56	1224	488	6388	1.4
G50	0-8	2.76	5.95	1.8		74		66		0.0
	8-24	2.38	6.91	0.2		45		38		0.0
	24-60	2.70	8.24	0.9	17	44	964	416	5232	0.3
W2	0-8	3.82	6.56	1.2		88		161		0.0
	8-24	4.10	7.25	0.1		71		351		0.0
	24-48	3.65	7.93	0.1	5	58	1080	491	6268	0.9
W4	0-2	2.53	6.13	2.7		84		71		0.0
	8 24	2.48	6.62	0.5		47		57		0.0
	24-60	2.13	6.95	0.6	17	40	956	40	972	0.0
W5	0-8	2.54	6.50	2.1		83		88		0.0
	8-24	1.88	6.80	0.2	7	34	400	37	432	0.0
W6	0-8	2.26	6.45	1.0		70		52		0.0
	8-24	1.77	6.50	0.2	4	34	368	35	328	0.0
W7	0-8	2.38	6.11	1.0		79		64		0.0
	8-30	2.26	6.64	0.2	5	45	544	61	620	0.0
W8	0-8	2.82	6.50	3.5		105		125		0.0
	8-24	2.46	6.81	0.3		44		48		0.0
	24-52	3.83	8.27	0.3	13	44	928	379	4124	2.5
W9	0-8	3.92	6.63	3.7		145		203		0.0
	8-24	4.12	6.80	0.5		53		113		0.0
	24-60	4.05	8.01	0.2	15	47	1236	427	6268	3.2
W10	0-8	3 18	6.57	3.2		106		157		0.0
	8-24	2.68	6.42	0.8		40		59		0.0
	24-60	3.20	8.24	0.2	15	48	1112	328	4612	0.0
O14	0-8	3.28	6.63	9.2		113		135		0.0
	8-33	2.65	7.79	0.4	28	46	688	407	3752	0.0
O15	0-8	1.58	6.33	1.7		93		66		0.0
	8-24	1.76	6.20	0.1	5	27	392	36	368	0.0
O17	0-8	2.73	6.44	2.4		91		129		0.0
	8-24	2.41	6.57	0.5	9	47	496	77	756	0.0
O18	0-8	1.93	7.01	1.7		79		94		0.0
	8-24	1.70	7.15	0.2	6	27	356	51	524	0.0
O19	0-8	2.19	7.42	1.9		85		167		0.0
	8-24	1.33	7.40	0.1	6	31	392	70	816	0.0

THE EFFECT OF LOOSE SMUT ON THE VIABILITY OF ARTIFICIALLY INOCULATED BARLEY SEEDS[1]

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INTRODUCTION

Loose smut of barley caused by *Ustilago nuda* (Jens.) K. and S. does not usually result in serious yield losses in western Canada. However, it is difficult to control and causes serious inconvenience in seed production. Resistance to this disease would be desirable in new barley varieties. Accordingly, varietal tests were instituted at this Station in 1944 to find parental material that carried resistance to the disease. When artificially inoculated seeds were planted many failed to emerge. Tests were then conducted to determine whether or not the loose smut organism was responsible for the reduced stands, and if so, whether or not varietal differences existed.

LITERATURE REVIEW

Several workers have encountered poor stands in seed artificially inoculated with loose smut.

Thren (6), using a dry spore method of inoculation, found that a high concentration of viable spores in the inoculum resulted in reduced stands and weak seedlings. He was able to increase stands and maintain good infection by reducing the live spore concentration. Some of his results were as follows:

Spore concentration	Per cent stand	Per cent infection
%	%	%
100	33 5	52.8
10	52 7	44.9
5	63 4	52.3
1	68.1	50.8
0.1	81.3	19.1
0	87.8	0.6

It will be noted that when a one per cent spore concentration was used there was still a considerable reduction in stand. In a later paper (7) Thren found that, with certain varieties, a low rate of infection at maturity was correlated with a heavy loss of inoculated material. This loss was partly due to failure of inoculated florets to develop seeds, but especially to failure of inoculated seeds to germinate. He considered that the resistance of these barleys was equivalent to hypersensitiveness to inoculation with the fungus. Such types were frequently found among Japanese varieties. Although with German varieties, Thren was able to decrease the loss of inoculated material by using the improved methods of inoculation described above, he was unable to do so with Japanese varieties.

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Livingston (1) also encountered poor stands from inoculated seed, and considered that infected plants were weakened by the loose smut organism.

Shands and Schaller (4) found that stands varied from year to year even though the same method of inoculation was used. By treating inoculated seed with an organic mercury dust they were able to increase germination and vigour. The dust, presumably, protected the seed from secondary fungi.

Oort (2), working with the loose smut disease of wheat, encountered symptoms of hypersensitiveness. Hypersensitive plants, when grown in the greenhouse, were inhibited in growth and frequently died in the two- or three-leaf stage. Those that survived remained small and produced little, if any, grain but were almost invariably free from smut. When grown in the field these plants usually failed to emerge. Oort concluded that two different principles were involved in the relationship of host to parasite, namely, resistance or susceptibility, and hypersensitiveness or non-hypersensitiveness. He attempted to explain the varietal reactions on the basis of genetic factors. The temperature prevailing during the ripening of the seed strongly influenced the degree of hypersensitiveness. For example, when Race 1 was used the degree of hypersensitiveness was about three times as high at 24° as it was at 13° C.

Vanderwalle (8) also worked with loose smut of wheat and found no correlation between the presence of the fungus in the seed and the ability of the seed to germinate. In so far as the authors are aware, he is the only worker who has not found a reduction in the germination of infected seed.

INOCULATION TECHNIQUE

Inoculum was collected from as many varieties as possible in the barley nursery plots. These varieties had been introduced over a period of years from many areas and were frequently infected with loose smut on arrival. Very probably the inoculum represents most of the prevailing forms of the organism.

The method of inoculation was similar to that outlined by Poehlman (3). The spores were removed from the rachis, put through a coarse sieve, and mixed with water in the proportions, one gram of spores to fifty c.c.'s of water. The suspension was mixed thoroughly and strained through cheesecloth. A one-ounce rubber bulb and a No. 24 hypodermic needle were used to inject the spore suspension into the florets. Inoculations were made one or two days after pollination of the earliest florets. All florets were inoculated except the small ones at the base and the tip of the spike.

EFFECT OF INOCULATION ON VIABILITY

A test was designed to determine whether or not reduced stands from inoculated seed were due to the loose smut organism or to the method of inoculation. Four varieties of barley were seeded in the greenhouse in January, 1946, and treated as follows: Twenty heads of each variety were inoculated with loose smut; twenty with tap water; the lemmas of twenty were punctured with the needle; and twenty were left as checks. The inoculated seeds were grown in the field, using a split plot design with four replicates.

A summary of the data obtained is presented in Table 1. The results clearly show that the presence of the loose smut organism caused a substantial reduction in stand. Inoculating with water or puncturing the lemmas had no significant effect on stand. There is evidence of varietal differences in the amount of reduction that took place. The stand of Conway, for example, was reduced much more than that of Plush.

TABLE 1.—STAND AND PER CENT INFECTION OF BARLEY VARIETIES INOCULATED WITH LOOSE SMUT COMPARED WITH UNINOCULATED CHECKS, CHECKS INOCULATED WITH WATER AND CHECKS IN WHICH THE LEMMA WAS PUNCTURED WITH A NEEDLE

Treatment	Variety	Per cent stand	Per cent infection
Check	Plush	78.0	0.0
Check	Conway	79.4	0.0
Check	Tregal	74.8	0.0
Check	Regal	69.5	0.0
Average		75 4	0.0
Lemma punctured	Plush	80.2	0.0
Lemma punctured	Conway	70.0	0.0
Lemma punctured	Tregal	80.8	0.0
Lemma punctured	Regal	70.8	0.0
Average		75.4	0.0
Inoculated with water	Plush	81.7	0.6
Inoculated with water	Conway	87.5	0.7
Inoculated with water	Tregal	75.7	0.3
Inoculated with water	Regal	71.7	1.7
Average		79.2	0.8
Inoculated with smut	Plush	45.2	63.9
Inoculated with smut	Conway	24.5	75.6
Inoculated with smut	Tregal	31.1	19.2
Inoculated with smut	Regal	43.7	19.7
Average		36.1	44.6

VARIETAL DIFFERENCES IN VIABILITY

Data were obtained on the stand and infection of 21 varieties in three different tests over the period 1944-46. Approximately 400 inoculated seeds were sown in each test. Unfortunately no comparable lots of seed were grown as checks. In the statistical analyses of the data obtained the value one was added to each of the figures for per cent stand and per cent infection in order to eliminate zero readings. The values obtained were converted to sine^2 θ and analysed by variance and covariance.

A summary of the actual data obtained is presented in Table 2, the variance analyses in Table 3, and the covariance analysis in Table 4.

Highly significant varietal differences were obtained for both stand and infection. Differences due to tests were significant for stands but not for infections. This would indicate that stands are more subject to environmental influences than infections.

The results of the covariance analysis showed that there was no relationship between stand and infection within varieties, since the difference between the mean square for error before and after adjustment was not significant. In other words, variations within varieties for per cent infection were not due to differences in stand. In addition, the covariance analysis showed a significant positive relationship between stand and infection between varieties, since the difference between the regressions within and between varieties was highly significant. That is, varieties with the best stands had the highest infection percentages. Exceptions, however, were found. For example, Warrior had a high degree of resistance and a fairly good stand, while Newal was very susceptible and had a poor stand.

TABLE 2.—STAND AND INFECTION PERCENTAGES OF BARLEY VARIETIES INOCULATED WITH LOOSE SMUT

Variety	Per cent stand				Per cent infection			
	Test 1	Test 2	Test 3	Av.	Test 1	Test 2	Test 3	Av.
Atlas	62.4	72.0	65.0	66.5	51.8	57.0	61.8	56.9
Rika	59.4	54.0	80.7	64.7	44.2	50.0	60.6	51.6
Plush	40.5	84.0	68.6	64.4	46.8	47.6	38.7	44.4
Trabut	61.1	46.0	74.2	60.4	53.2	56.5	43.1	50.9
Vantage	57.9	59.0	64.2	60.4	34.8	49.2	45.3	43.1
U. of S. 8	52.1	60.0	61.4	57.8	34.0	43.3	34.7	37.3
Mars	69 4	46.0	53.6	56.3	31.0	19.6	27.9	26.2
Warrior	44.8	58.0	63.6	55.5	6.4	0.0	1.6	2.7
Brandon 1360	46.7	56.0	61.4	54.7	54.0	44.6	61.0	53.2
Brandon 112	50.0	60.0	47.9	52.6	51.2	40.0	39.8	43.7
O.A.C. 21	38.1	55.0	64.3	52.5	0.0	20.0	23.3	14.4
Hannchen	39.8	53.0	60.7	51.2	56.5	51.0	59.4	55.6
Tall Comfort	39.6	53.0	53.6	48.7	8.9	7.5	6.9	7.8
Regal	33.1	60.0	52.8	48.6	18.9	15.0	17.5	17.1
Texan	49.4	40.0	56.4	48.6	0.0	2.5	2.5	1.7
Montcalm	40.5	48.0	56.4	48.3	52.6	18.8	39.1	36.8
Trebi	57.7	39.0	42.1	46.3	0.0	5.1	5.2	3.4
Velvon	39.3	49.0	45.7	44.7	3.8	14.3	22.0	13.4
Titan	39.4	49.0	42.1	43.5	0.0	0.0	0.0	0.0
Newal	32.5	40.0	34.3	35.6	47.8	50.0	51.1	49.6
Ezond	34.2	26.0	19.3	26.5	0.0	0.0	0.0	0.0

TABLE 3.—ANALYSES OF VARIANCE OF STAND AND INFECTION

Variation due to	Degrees of freedom	Stand		Infection	
		Mean square	F value	Mean square	F value
Tests	2	137.40	4.30*	28.17	1.07
Varieties	20	99.14	3.10**	757.25	28.88**
Error	40	31.96	—	26.22	—

* Exceeds the 5 per cent point.
** Exceeds the 1 per cent point.

TABLE 4.—ANALYSIS OF COVARIANCE

Source	Deg. of freed.	Sums of squares and products			Errors of estimate			
		Sx^2	Sxy	Sy^2	Sums squares	D.F.	Mean square	F
Total	62	3,535.77	3,275.48	16,250.24				
Tests	2	274.79	110.88	56.34				
Varieties	20	1,982.77	3,128.33	15,144.99	10,209.25	19		
Error	40	1,278.21	36.27	1,048.91	1,047.88	39	26.869	
Var. plus error	60	3,260.98	3,164.60	16,193.90	13,122.84	59		
Difference for testing adjusted variety means					12,074.96	20	603.748	22.47**
Difference between regressions within and between varieties (b_1—b_2)					1,865.71	1	1,865.71	69.44**
Difference between errors before and after adjustment					1.03	1	1.03	0.04

r_1 (Between varieties) = 0.571**.
b_1 (Between varieties) = 1.58.
r_2 (Within varieties) = 0.031.
b_2 (Within varieties) = 0.028.

** Exceeds the 1 per cent point.

DESTRUCTION OF EMBRYOS

In the course of work on the host-parasite relationship evidence was obtained that the mycelium of the loose smut disease was capable of completely destroying barley embryos. The destruction or weakening of them probably accounts for the losses in viability that have been noted. A brief description of the relevant parts of this investigation follows.

In 1945, twenty varieties were inoculated in the field. When harvested, the inoculated seed from each spike was divided into two lots. This was done by placing the seeds from one side of each spike in one lot and those from the other in the second lot. There were approximately 100 seeds of each variety in each lot.

One lot of seed was planted in the greenhouse and the stand and infection noted.

The second lot was examined for the presence of mycelium in the embryos by means of the "whole embryo method" described by Simmonds (5). Using this technique the embryos are removed from the endosperms by treatment with a sodium hydroxide solution. They are then dehydrated in alcohol, cleared in cedar oil and examined without staining or sectioning. In the present study, glycerine was used as a clearing agent instead of oil, and as a result, it was not necessary to dehydrate with alcohol. The glycerine modification simplified the technique, but specimens could not be kept in good condition for as long a period of time.

When the embryos were examined, it was found that some had been almost completely destroyed by the invading mycelium. Such badly injured embryos would have little chance of producing seedlings. No attempt was made to determine the number of badly damaged embryos in

TABLE 5.—PERCENTAGE OF EMBRYOS RECOVERED BY THE WHOLE EMBRYO TECHNIQUE AND PERCENTAGE STAND FROM COMPARABLE LOTS OF SEED GROWN IN THE GREENHOUSE

Variety	Per cent embryos recovered	Per cent stand
Plush	92	84
Glacier	78	65
Lico	87	64
Warrior	98	58
Brandon 1360	80	56
O.A.C. 21	80	55
Colsess	84	53
Hannchen	75	53
Tall Comfort	83	53
Velvon	64	49
Titan	70	49
Rex	66	47
Mars	72	46
Trabut	98	46
Newal	83	40
Trebi	70	39
Vance Smyrna	35	30
Ezond	38	26
Tregal	36	20
Conway	54	15
Average	72	47

$r = 0.769$ (Significant at the 1 per cent level).

relation to more normal appearing ones. Generally speaking, there was a gradation within each variety from severe injury to no evidence of mycelial growth. However, it was noted that where embryos of resistant types were infected, the amount of apparent damage was much greater than in the more susceptible types.

When the embryos were removed from the endosperms, every precaution was taken to recover all of them. Despite these precautions, only a portion of them were recovered. From a physical examination it appeared that the loss in recovery was primarily due to destruction by the loose smut organism so that the embryo disintegrated and was lost in the recovery process. The percentage of embryos recovered was compared with the percentage stand of the first lot of seed grown in the greenhouse. The data are presented in Table 5. A highly significant correlation coefficient of 0.769 was obtained between the two variables. This is further evidence in support of the hypothesis that the loose smut organism is capable of destroying the embryos of barley. The mean percentage of embryos recovered was 72 and the mean percentage stand was 47. The difference was probably due to the fact that a portion of the embryos recovered were badly damaged, and to mortality from other causes, such as secondary disease organisms.

DISCUSSION

The results of this study are in agreement with other investigators that inoculating barley with loose smut results in lowered viability of the seed. The reduction is apparently due to the mycelial growth destroying the embryo or, as Oort (2) has termed it in wheat, the plant is hypersensitive to the organism. The amount of reduction appears to depend on a number of factors.

Variety

The present investigation has shown that varieties differ in the amount of damage they sustain.

Spore Load

Heavy spore loads cause greater reductions according to Thren (6).

Environmental Conditions Following Inoculation

Oort (2) has shown that temperature at this time influences the degree of hypersensitiveness of wheat to loose smut and very probably the same thing occurs in barley.

Environmental Conditions Following Seeding

As would be expected, practically all investigations, including the present one, show differences between tests that are probably due to environmental conditions at the time of germination and early seedling growth.

Physiologic Specialization

Oort (2) found that symptoms of hypersensitiveness were induced by five out of ten collections representing three out of six physiologic races of loose smut on wheat. Thren (7), on the other hand, working with two races of loose smut of barley, found no significant difference between them in decrease in germinability of inoculated seeds of the differential host, Mittlauer Hanna. Different results might easily have been obtained using other races or host varieties.

It is obvious that the amount of infection that a variety exhibits at maturity is dependent not only on its inherent resistance, but also on its ability to grow when the embryo is infected. In this study, these factors were positively associated, but the association was not close. Somewhat similar results were obtained by Thren (7). The interrelationships of these two phenomena need further study. It is hoped that a genetical study, now under way at this Station, will throw further light on the problem.

The reduced viability of inoculated seed probably explains the results of certain cultural experiments on this disease. For example, deep seeding has frequently been found to result in less loose smut in the crop than shallow seeding. It would be expected that fewer infected plants would emerge from the greater depth.

SUMMARY

Four varieties of barley were treated as follows. One lot of each variety was florally inoculated with chlamydospores of the loose smut organism *Ustilago nuda* (Jens.) K. and S. by means of a hypodermic needle; a second was inoculated with tap water; in a third the lemmas were punctured with the needle; and the fourth was left as a check. Compared with the check, the emergence of seeds inoculated with the organism was much lower, whereas those inoculated with water, or where the lemma was punctured were equally as high.

Approximately 400 seeds of each of 21 varieties were inoculated in a second experiment. In all, three such tests were conducted. Significant differences due to varieties and to tests were established. A significant positive relationship was established between stand and infection at maturity.

An examination of the embryos of inoculated seed showed that some embryos were almost completely destroyed by the invading mycelium. The percentage of embryos that could be recovered after treatment of the seed with sodium hydroxide was noted. Non-recovered embryos were presumed to have been destroyed by the fungus. A highly significant positive correlation of 0.769 was found between percentage of embryos recovered and percentage stand of comparable lots of seed.

It is pointed out that the amount of infection present on a variety at maturity depends not only on inherent resistance, but also on the ability of the seed to germinate and grow when the embryo is infected. Both factors need to be taken into consideration when the genetics of loose smut resistance in barley are studied.

ACKNOWLEDGMENTS

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CHEMICAL METHODS OF MEASURING DDT[1]

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Advances in chemical methods for the control of insects have resulted from application of the techniques of chemistry and entomology to the problems of insect control. Nowhere is this better exemplified than in the development of DDT. From the entomological point of view, one of the most important contributions from chemistry is the development of quantitative methods for measuring DDT. These methods offer a valuable tool to the research entomologist and they are finding many applications in entomological research.

With the object of extending the entomologist's acquaintance with chemical approaches to his problems, this paper reviews the role of chemical methods for measuring DDT in insecticide research, and discusses the principles and salient features of some of these methods.

THE ROLE OF CHEMICAL METHODS IN DDT STUDIES

The simplest form of the common proposition in insecticide research is: How much insecticide is required to kill a certain insect? The condition "how much" requires a quantitative definition; but the result, "dead" or "alive", is a qualitative description of the gross biological response to the insecticide. Recognition of this dual relation reveals the necessary association of quantitative chemical methods with bioassay procedures in insecticide research. Chemical methods are used to define the principal condition of such investigations—that is, the quantity of insecticide to which the insects are exposed; but their response to that quantity of insecticide can be assessed only by bioassay methods.

Both methods are involved even though only one of them is specified. Thus, the entomologist studying the effect on insects of a proprietary 5 per cent DDT formulation may not analyse the insecticide, but he assumes that the manufacturer did so and found it to contain 5 per cent DDT. Conversely, the DDT residue on apples may be determined by chemical analysis and reported as more or less than the tentative tolerance of 7 p.p.m., but this result is ultimately referrable to tolerances established with experimental animals.

Bioassay methods are essential to the investigation of the insecticidal effects of DDT. There is no other way to measure "insecticidal effect" than by observing the response of the specific insect concerned. This truism needs no more demonstration than the observed resistance of the

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Mexican bean beetle and the susceptibility of the housefly to DDT. The difficulty with bioassay experiments is essentially the difficulty of defining the conditions of the experiment. The principal condition is the quantity of DDT to which the test insects are exposed. But the insect response may be greatly modified by the complex factors represented by the physical state of the insecticide, the conditions of exposure, and the sex, age, previous environment and genetic constitution of the insect itself. Obviously, bioassay procedures rest on an intricate foundation. Precision depends on the extent to which the variables can be defined and controlled.

Chemical methods of measuring DDT enable accurate definition of one of these variables—the amount of insecticide to which the insects are exposed. Information on how much insecticidally active DDT is present in formulations, residues, and biological systems is basic to investigations with DDT. Whether the investigation is concerned with testing the insecticidal value of a series of DDT formulations, with seeking the most effective dosage, or with studying the effect of environmental factors on DDT residues, an essential question is how much DDT is available to kill insects. Similarly, studies of the longevity of DDT residues are concerned with how long a deposit will retain the amount of active DDT necessary to kill insects. Quantitative determination of DDT in absolute units fixes the common variable in such studies.

It must be emphasized that the amount of DDT dispensed is not necessarily equivalent to the amount deposited; indeed, the amount deposited may not be the amount available to kill insects. Thus, in both laboratory and field tests, some of the DDT dispensed may not reach the target. This fact is generally recognized and it is a common procedure to weigh the actual deposit and to calculate, from the DDT content of the formulation, the weight of DDT deposited. The assumption is made that the deposit contains the same proportion of DDT as the initial formulation, but this may not be assumed with certainty. Even when the deposit of DDT is known with certainty, absorption by the surface of the substrate may reduce the residue available to contact by insects. Chemical determination of the amount of DDT at the time and site of insect contact provides the most reliable measure of this factor.

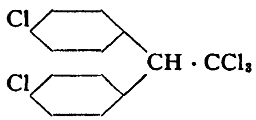
Not only the amount but also the isomeric form of DDT requires definition, and is accessible to chemical determination. The insecticidal action of DDT is mainly due to the para para isomer, and this isomer may be measured with reasonable specificity by one of the methods described in a later section. The influence of factors such as time, temperature, and chemical compounds on the insecticidal effect of DDT may be anticipated therefore by their effect on the para para isomer. Thus, thermal degradation, photodecomposition, and catalytic breakdown of DDT may be measured and ascribed as conditions modifying the insecticidal effect.

It may be objected that there is little advantage in knowing the actual amount of para para DDT to which the insect is exposed, that the essential information lies in the relation between the quantity of DDT dispensed and the observed mortality. This is true when the object of the investigation is to provide a basis for practical control measures and no further information is sought. But new approaches are opened by studies designed to evaluate the many variables in the seemingly simple relation between

observed mortality and DDT applied. Such variables, which are inevitably present in bioassay procedures, can only be evaluated when the amount and isomeric form of DDT are accurately known.

CHEMICAL METHODS OF MEASURING DDT

The term "DDT" does not refer to a specific chemical compound. There are 45 possible compounds (stereoisomeric forms not included), all of the same molecular formula, $C_{14}H_9Cl_5$(10), and with the same generic name, dichlorodiphenyltrichloroethane. The most abundant and most toxic isomer in commercial grade DDT is the para para isomer, called p,p′-DDT for short, but which is properly named *2,2 bis (p-chlorophenyl) 1,1,1-trichloroethane.* Basically it is an ethane molecule, with its hydrogens substituted in certain places by chlorophenyl and chlorine groups. The structural formula of this para para isomer is shown below.



p,p′-DDT

As commonly used, the term "DDT" refers to commercial grade DDT which contains a mixture of isomers and related compounds in which p,p′-DDT occurs in quantities from 75 per cent to 95 per cent (14), (20).

Chemical methods of measuring DDT may be placed in three groups:

Gravimetric Methods. The DDT content of the sample is measured by weighing the p,p′-DDT crystals yielded by crystallization procedure.

Volumetric Methods. The DDT undergoes molecular fission and is stoichiometrically represented by one or more of its constituent atoms. The quantity of such representatives derived from a given sample is determined by suitable titration procedures.

Colorimetric Methods. The DDT molecule is chemically altered to yield a compound with a characteristic colour, the intensity of which is proportional to the amount of DDT originally present. The colour intensity is measured photometrically at the wavelength of its max mum absorption.

The principles and salient features of methods representative of these groups follow:

Gravimetric Methods

Crystallization of p,p′-DDT

This method as described by Cristol, Hayes and Haller (9) is especially useful for assay of technical grade DDT and DDT dusts.

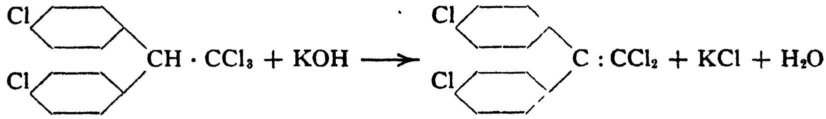
A given weight of the unknown is refluxed with a suitable amount of 75 per cent ethanol which has been saturated with p,p′-DDT at room temperature. After refluxing, the solution is cooled to room temperature whereupon the p,p′-DDT of the unknown crystallizes out quantitatively because the ethanol solution had been previously saturated with p,p′-DDT at that temperature. The crystals are suction-filtered, dried at 80° C., weighed, and calculated as the p,p′-DDT content of the sample. A melting point determination provides a check on crystal purity (m.p. = 106° C. is satisfactory). When a small empirical correction is added, this gravimetric method is stated to be reliable to ± 1 per cent.

Volumetric Methods

Labile Chlorine

This method is based on the DDT property originally observed by Zeidler (22) in 1874. As described by Gunther (13) it is simple, rapid, and suitable for residue analysis in the range 1-15 p.p.m. (20), provided an adequate sample is available, and the nature and amount of labile chlorine-containing compounds other than DDT are known.

One of the five chlorine atoms of the DDT molecule is labile, and is detachable by hydrolysis in the presence of alkalis, involving a loss of one molecule of hydrogen chloride from the parent DDT structure. The breakdown product *2,2 bis (p-chlorophenyl) 1,1-dichloroethylene* (DDX) is formed. Thus:



DDT *DDX*

The labile chlorine atom, having become an inorganic chloride by "dehydrochlorination", is then measured by the Volhard titration method or electrometrically. Since one chlorine atom is measured, and since this represents 10 per cent of the molecular weight of DDT (354.5), results are multiplied by 10. Reproducibility is $\pm$ 0.17 mg. in the range 1.7-26 mg. (20).

Sulphur and plant materials can be important interfering factors. Baier *et al.* (1) developed a modified dehydrochlorination method for residues containing as much as 90 per cent sulphur. In a study of DDT dehydrochlorination, Wain and Martin (19) showed that reaction temperature and alkali strength lower than used by Gunther promoted analytical accuracy.

Compounds lacking labile chlorine atoms do not interfere—DDX, DDD, DDA and dichlorobenzophenone, for instance. However, other DDT isomers, hexachlorocyclohexane, chlorinated camphene, chlordane, and some other chlorinated insecticides also have labile chlorines, thus limiting the interpretation somewhat. A labile chlorine procedure has been used for total BHC assay, where only hexachlorocyclohexane was known to be present (12).

Total Chlorine

Methods based on total chlorine determination are widely used for measuring DDT residues on agricultural crops and in the determination of DDT content of sprays, dusts, and other formulations.

All five organically bound chlorine atoms are converted to inorganic chlorides by reduction with metallic sodium in benzene in the presence of isopropanol as catalyst. The resulting sodium chloride is estimated by standard titration methods, usually the Volhard method, or electrometrically. Results are multiplied by 2 since the five chlorine atoms

measured constitute 50 per cent of the molecular weight of DDT. Reproducibility of ± 0.05 mg. in the range 0.5–8.0 mg. is reported in a comparative study by Wichmann *et al.* (20).

Total chlorine methods are not specific for DDT in the presence of other chlorine-containing compounds. All DDT isomers, hexachlorocyclohexane, 2,4-D, DDX, and similar substances will interfere. Therefore it is important to establish that the chlorine-containing material is DDT.

Carter and Hubanks (4) have shown that the rate of decomposition of DDT in residues may be measured by determining both labile and total chlorine respectively in a given sample. The ratio Labile Chlorine: Total Chlorine for undecomposed DDT is 0.20 theoretically. Values lower than this indicate DDT breakdown. This combined technique was applied in determining the effect of light (6) and temperature (11), (21) on DDT residues.

COLORIMETRIC METHODS

Xanthydrol-Pyridine-KOH Reaction

This method, described by Stiff and Castillo (17), is rapid and sensitive. In addition it is adaptable for qualitative and rough quantitative field operations (18).

DDT heated in anhydrous pyridine containing xanthydrol and solid KOH yields a red colour. The intensity of this colour at a wavelength of 520 mμ is proportional to the amount of DDT present. This method is sensitive to 10 micrograms (mmg.) of DDT and is quantitative in the range 10–240 mmg. The chemistry of the test is not known.

This method does not distinguish between DDT and DDX. It is selective for DDT in the presence of DDD (7). The red colour is given by compounds having the structure $> CHCX_3$ or $> C = CX_2$ (15). The xanthydrol-pyridine-KOH reagent must be prepared daily. A number of critical features such as time, temperature, and moisture limits must be observed.

Nitration Reaction

This is usually called the Schechter-Haller method (16). The dried DDT residue is intensively nitrated, thereby yielding a tetra-nitro derivative. After isolation of the tetra-nitro DDT, involving a number of steps, it is dissolved in a known amount of benzene. Upon adding a definite volume of methanolic sodium methylate to the benzene solution a reasonably stable blue colour results, showing maximum absorption at 600 mμ, the intensity of which is proportional to the amount of p,p′-DDT present. This method may also be used to determine o,p′-DDT, which gives a violet-red colour with two absorption peaks at 590 and 510 mμ, respectively.

To date, this method is the most specific and sensitive for p,p′-DDT. While it cannot differentiate between p,p′-DDT and DDD, it can measure p,p′-DDT, o,p′-DDT, and DDA in the presence of each other. It is negative to DDX. Using this method, one of the authors (B.B.) has detected 5 mmg. in DDT residues and has found reproducibility of ± 1 mmg. in the working range 10–125 mmg. With certain modifications, Clifford (8) has adapted the method for the micro range 0–50 mmg.

A complete catalogue of colorimetric methods for DDT analysis would include a number of other tests, such as the Friedel-Crafts reaction (2); H_2SO_4—glacial acetic reaction (5); hydroquinone—H_2SO_4 reaction (3), and the 2,4-dinitrophenylhydrazine reaction (20). They serve to illustrate the varied colour reactions to which the DDT molecule is amenable.

A word about analytical preference is in order. Each method varies with regard to specificity, sensitivity, reproducibility, and response to interfering substances (fats, waxes, plant resins, organic sulphur, chromogenic compounds, etc.) Choice of a given method must be predicated on conditions of the particular investigation, such as sample size, total residue per sample, nature and amount of substances present other than DDT, and level of reproducibility desired.

SUMMARY

Bioassay methods are indispensable to insecticidal evaluation of DDT. However, the complex of variables associated with biological assay makes accurate interpretation difficult. The principal variable is the amount of DDT present at any given time, and this is amenable to exact determination by chemical methods. Such knowledge can be useful as an absolute reference point for improving the precision of bioassay techniques.

A number of chemical methods for measuring DDT are available which provide the entomologist with procedures suited to a wide range of entomological problems. The economic and biologic importance of DDT require utilization of the most precise research methods. In this capacity chemical methods of DDT measurement are playing an increasingly important role.

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REACTION OF BARLEY VARIETIES TO SPRING FROST[1]

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While spring frost cannot be listed among the more important factors limiting cereal production, it can on occasion be responsible for widespread damage. In extreme cases, losses may be so severe as to necessitate reseeding; in less severe cases the crop may be badly thinned, enabling weeds to gain the ascendancy; and in still other cases, losses may be reflected in reduced yields caused by delayed maturity forcing the crop to mature in a less favorable period of the growing season.

It is a generally accepted fact that barley is more readily damaged by spring frost than wheat. The barley breeder is cognizant of this fact and is interested in incorporating as high a degree of frost resistance as possible into his hybrid productions. He has been somewhat handicapped in this regard because of comparatively meager information available on the reaction of barley varieties to freezing temperatures, particularly in the case of those varieties developed during the past ten or twelve years. The work of Harrington (1) carried out under natural conditions, and of Platt (3) using chambers cooled by refrigeration, showed that varieties differ quite markedly in their capacity to survive freezing temperatures.

An excellent opportunity to augment the known information on frost resistance of barley varieties presented itself on the night of May 27, 1947, when, following several abnormally cool days, the temperature dropped at many points in western Canada to well below the freezing-point. Extensive damage to crops and gardens resulted. Included in the area covered by this frost were the Dominion Experimental Stations at Swift Current, Sask., and Scott, Sask.; and the Dominion Experimental Farm at Brandon, Man. At all three points, careful notes were taken on frost damage to cereal varieties. A comparison of these data revealed that a particularly good differential reaction was indicated in the case of barley and at the same time a decision was arrived at to summarize the data for publication.

METEOROLOGICAL CONSIDERATIONS

A feature of the frost in question was its long duration. At many points, freezing temperatures set in an hour or two before sunset and continued until several hours after sunrise the following morning. It is also noteworthy that this frost was immediately preceded and followed by several other frosts of lesser intensity.

Temperature Data at Scott, Sask.

The following minimum temperatures were recorded at Scott: May 25, 24.5° F.; May 26, 17.0° F.; May 27, 12° F.; and May 28, 15° F. The maximum temperature recorded on May 27 was 40° F. The temperature dropped to freezing by 5 p.m. and continued freezing until 9 a.m. of

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the morning of May 28—a duration of sixteen hours. This frost was considered to have caused the most damage but there was no doubt that four continuous nights of frost aggravated the situation.

Following the frost, comparatively warm weather with maximum temperatures ranging around 65°-70° F. occurred and the first shower (.36 inches) was recorded on June 4—one week after the frost. Recovery of all barley varieties was fairly good but the later maturing types suffered in comparison with early maturing types by being forced to head out during a dry, hot period, which prevented the heads from emerging from their sheaths in some instances.

Temperature Data at Swift Current, Sask.

Frosts were recorded on three successive nights as follows: May 26, 9° F.; May 27, 14° F.; and May 28, 5° F. The maximum temperature on May 27 was 44° F. It was estimated that the frost was of about twelve hours' duration. Conditions following the frost were favorable for rapid recovery. Temperatures remained relatively low and a shower of rain (.20 inches) was received on May 30. All varieties apparently recovered completely.

Temperature Data at Brandon, Man.

Frost was recorded on six successive nights. The temperatures were: May 24, 21.8° F.; May 25, 26.5° F.; May 26, 22.7° F.; May 27, 15.9° F.; May 28, 22.5° F.; and May 29, 30.4° F. On the night of May 27 when the bulk of the damage occurred, freezing temperatures commenced at 8 p.m. and continued throughout the night until 8 a.m. the next morning. A week of cool weather following the frost enabled the barley to make quick recovery. On June 8, approximately one inch of rain fell. The only permanent injury noted was in the case of a few varieties that had suffered over 80 per cent foliage loss. In these instances, tillering was sparse, the plants failed to regain normal vigour, and yield was noticeably reduced.

GENERAL METHODS

At all three Stations, frost susceptibility was expressed in terms of per cent foliage killed. The individual plant was used as the basis of measurement but only a single estimate was made for each plot. The readings were made within two or three days of the frost before any visible signs of recovery were evident.

While some differences existed among the several tests as to the stage of growth of the barley at the time of the frost, for the most part the plants were in what is commonly referred to as the three- to four-leaf stage.

In applying the analysis of variance method for determining significance, percentage data from the Brandon and Swift Current tests were transformed to degrees. The Scott data were not transformed since none of the percentages was particularly low or high (2).

A six replicate uniform barley test conducted at many points in Western Canada and known as the National Barley Test was caught by frost at all three Stations. Since the frost readings obtained offered an

interesting comparison of varietal reaction, these data have been grouped in a single table. In addition to the National Barley Test, notes were taken at Swift Current on the Great Plains Nursery and on eight Supplementary Barley Tests located at some distance from the Station. At Brandon, readings were also made on the varieties in the Manitoba Co-operative Barley Test and on selections in two large hybrid tests. At Scott, frost readings were made on a group of seven varieties not represented in the National Barley Test.

EXPERIMENTAL DATA

National Barley Test

This test is conducted under the jurisdiction of the Sub-Committee on Plant Breeding and Production of the National Barley Committee and has as its chief objective the testing of promising hybrids developed in Canada as well as new varieties that have gained prominence in the United States. Several recommended varieties are included for purposes of comparison. In 1947, the test consisted normally of twenty-five varieties. However, at some stations, extra varieties were added to meet local needs. This will explain the presence of thirty-three varieties in the Swift Current test compared with only twenty-five in the tests at Brandon and Scott.

The frost damage data compiled at the three Stations have been summarized in Table 1. It will be noted that highly significant varietal differences were established at Brandon and Swift Current, whereas at Scott these differences only exceeded the level of significance by a relatively small margin. The greatest range of varietal reaction was obtained at Brandon where actual per cent foliage damage varied from 8 per cent and 9 per cent in the case of the varieties Compana and Bay to 89 per cent in the case of the University of Alberta hybrid 43-46. A good agreement exists between the Brandon and Swift Current data. The varieties Compana, Bay, Tregal, Titan, OAC. 21, UM. 1522 and Ottawa 2526A are among the highest ranking for frost resistance at both Stations. Similarly, the three University of Alberta selections—as well as Frontier, Montcalm and Velvon 11—are among the most susceptible. The varieties Feebar and Br. 3950-1136 were rated relatively more resistant at Swift Current than they were at Brandon.

While the results obtained at Scott are in general agreement with those obtained at the other two points, there are a few exceptions. The variety Bay, which showed good resistance at Brandon and Swift Current, was one of the more susceptible at Scott. Titan was also rated as being relatively more susceptible. On the other hand, the three Brandon selections (notably Br. 3950-1239) were more resistant at Scott than at the other Stations. However, the analysis of the data shows that the frost damage at Scott was not nearly so uniform as that at the other two stations. The standard error, as well as the minimum significant difference, was considerably higher at Scott. Thus although discrepancies do occur between the Scott data and the rest, the rank of the varieties based on the minimum significant difference is not changed as much as the actual damage ratings would indicate.

With reference to the eight additional varieties grown in the Swift Current test, the high resistance shown by Vance Smyrna is noteworthy.

In fact, this variety showed the least foliage loss of the thirty-three tested at that Station. Trebi and Rex rank in resistance about equal to Titan or Tregal. The remaining varieties would be classified as "susceptible" or "moderately susceptible".

TABLE 1.—SPRING FROST DAMAGE TO BARLEY VARIETIES GROWN IN THE NATIONAL BARLEY TEST AT BRANDON, MAN., SCOTT, SASK., AND SWIFT CURRENT, SASK., IN 1947

Variety	C.A. number	Per cent foliage loss					Average
		Brandon		Scott	Swift Current		
		Actual	Transformed	Actual	Actual	Transformed	Actual
Compana	1154	8	15.7	30	20	26.6	19.3
Tregal	1150	13	20.6	22	30	33.1	21.7
Ott. 2526A	94	20	26.5	20	28	32.0	22.7
OAC. 21	1086	15	22.8	20	38	38.2	24.3
UM. 1522	41	16	23.3	24	37	37.2	25.7
Titan	1164	15	22.7	40	27	31.0	27.3
Ott. 2206B	93	21	26.9	22	45	42.1	29.3
Bay	112	9	17.3	58	22	27.7	29.7
Plush	1117	25	29.8	30	47	43.1	34.0
Br. 3957-154	101	26	30.5	25	53	46.9	34.7
Vantage	1162	21	27.1	40	48	44.0	36.3
Br. 3950-1239	102	44	41.6	18	60	50.8	40.7
Br. 3950-1136	1167	46	42.6	30	48	44.0	41.3
Glacier	1149	36	36.7	31	57	48.9	41.3
Feebar	113	32	34.2	58	38	38.2	42.7
Br. 3951-1360	1163	46	42.6	30	72	57.9	49.3
Gem	111	45	42.1	59	50	45.0	51.3
Velvon 11	1151	49	44.5	45	67	56.9	53.7
Newal	1089	55	47.9	55	62	51.8	57.3
UM. 856	114	40	39.2	68	65	53.8	57.7
Montcalm	1135	51	45.5	56.	70	57.0	59.0
Frontier	110	57	48.9	57	70	57.0	61.3
U of A 42-24	96	83	65.9	60	78	62.6	73.7
U of A 43-10	95	83	65.9	59	82	65.0	74.7
U of A 43-46	97	89	71.2	62	90	73.3	80.3
Vance Smyrna	134	—	—	—	10	18.4	—
Trebi	753	—	—	—	27	30.9	—
Rex	1113	—	—	—	30	33.2	—
Warrior	1144	—	—	—	48	44.1	—
Br. 3950-1986	135	—	—	—	52	46.0	—
Prospect	1140	—	—	—	57	48.9	—
Ab. 36-1991	136	—	—	—	65	53.8	—
Atlas	702	—	—	—	65	53.8	—
Statistics:							
Mean	—	—	37.3	34.7	—	45.2	—
SE in per cent	—	—	4.50	17.3	—	3.65	—
Min. Sign. Diff.	—	—	4.75	19.0	—	4.66	—
F value	—	—	74.80	3.41	—	54.32	—
Five per cent pt.	—	—	1.60	1.60	—	1.14	—

NOTE: UM—University of Manitoba.
Ott—Cereal Division, Central Experimental Farm, Ottawa.
U of A—University of Alberta.
Br—Dominion Experimental Farm, Brandon, Man.

Great Plains Barley Nursery, Swift Current, Sask.

The spring frost ratings on the varieties comprising this test have been summarized in Table 2. Varieties have been arranged in ascending order of susceptibility. Each of the values given is the mean frost reading from three replicates. The statistical analysis reveals that the varieties Munsing and Titan, while not differing significantly among themselves, suffered significantly less foliage damage than did any of the other varieties in the test with the exception of Tregal. On the other hand, the Velvon selections, as a group, showed high susceptibility. The uniform results obtained in the case of these Velvon strains reflect favorably on the reliability of the data presented.

TABLE 2.—SPRING FROST DAMAGE TO BARLEY VARIETIES COMPRISING THE GREAT PLAINS NURSERY, GROWN AT SWIFT CURRENT, SASK., 1947

Variety	C.I. number	Per cent of foliage loss	
		Actual	Transformed
Munsing	6009	23	28.8
Titan	7055	23	28.8
Tregal	6359	30	33.0
Nebr. 381162	7114	40	39.1
Nebr. 383999	7261	43	41.1
Nebr. 383576	7263	43	41.1
Nebr. 383962	7262	47	43.1
36Ab. 2031	7152	47	43.1
Atlas 46	7323	47	43.1
SD. 385	7260	47	43.1
Spartan	5027	50	41.7
SD. 252	7250	53	46.9
Beecher	6566	60	50.8
Gem	7243	60	50.8
Velvon BC_4-68	—	63	52.8
36Ab. 6127	7008	63	52.8
Flynn 37	5918	67	54.8
Velvon BC_4-15	—	67	55.1
Club Mariout	261	70	56.8
H.C. 41-94	7258	70	56.8
Flynn 1	5911	70	57.0
Velvon BC_4-12	—	73	59.0
Velvon BC_4-51	—	73	59.0
Velvon 313	—	73	59.0
Velvon 11	7088	73	59.0
Velvon BC_4-6	—	77	61.2

Mean—48.9 SE in %—5.75 Min. Sig. Diff.—7.95 F value—11.63 5 per cent point—1.74

Supplementary Barley Test, Swift Current, Sask.

Notes on frost reaction were taken on a group of eight tests conducted by the Dominion Experimental Station, Swift Current, in the region served by that institution. Six of these tests comprised a uniform set of six varieties. It will be noted from the summarized data presented in Table 3 that considerable variation existed from point to point in the degree of damage that resulted. Highly significant varietal responses were demonstrated for each test and these are consistent with those already noted. In order to check statistically on the possibility of differential varietal response,

TABLE 3.—SPRING FROST DAMAGE TO BARLEY VARIETIES GROWN AT EIGHT LOCATIONS IN 1947 BY DOMINION EXPERIMENTAL STATION, SWIFT CURRENT, SASK.

Location		Per cent foliage loss resulting to						Statistics				
		Titan	Velvon 11	Tregal	Vantage	36Ab-1991	Compana	Mean	SE in %	Nec. Diff.	F value	5% point
Shaunavon	Actual	42	80	22	45	80	35					
	Transformed	40.7	63.8	28.3	42.1	63.8	36.2	45.8	3.91	5.06	67.81	2.90
Valjean	Actual	68	82	50	48	88	35					
	Transformed	55.3	65.9	45.0	43 6	69.6	36.2	52.6	2.07	3.10	145.86	2.90
Riverhurst	Actual	30	40	25	22	38	20					
	Transformed	33.2	39 2	29.9	28.3	37.7	26.6	32.5	4.69	4.31	11.34	2.90
Vidora	Actual	66	79	44	65	78	53					
	Transformed	54.2	62.9	41.6	53.8	61 8	46.7	53.5	1.77	2.69	77.97	2.90
Fox Valley	Actual	50	78	30	55	72	38					
	Transformed	45.0	61.8	33.2	47.9	58.5	37.7	47.3	3.06	4.10	59.97	2.90
Kyle	Actual	42	70	30	45	65	35					
	Transformed	40.7	57.0	33.2	42.1	53.8	36.2	43.8	3.34	4.14	42.85	2.90
Carmichael	Actual	25	52	22	45	50	—					
	Transformed	29.9	46.5	28.3	42.1	45.0	—	38.3	4.25	4 61	28.02	3.26
Tugaske	Actual	40	42	25	22	45						
	Transformed	39.2	40.7	29.9	28.3	42.1	—	36.0	4.52	4.61	15.71	3.26
Average	Actual	43.4	65.4	31.0	43.4	64.5	36.0					
	Transformed	42.5	54.7	34.9	41.0	52.8	36.6					

the data for the six stations having a uniform set of varieties were combined and analysed by the variance method. The Chi-square test as proposed by Bartlett (2) was applied to the six estimates of variance involved and they were found to be homogeneous (P lying between .50 and .20).

The results revealed a significant interaction between variety and Station (F—5.27; 5 per cent point—1.64) which would indicate that all varieties had not responded similarly at the different Stations. It was also found, however, that the variance of variety means significantly exceeded that of variety and Station interaction (F—29.52; 5 per cent point—2.60). It would appear, therefore, that, despite some differential response, varietal reaction generally was consistent enough to enable the establishment of definite variety differences. It may be assumed that the resistance shown by Compana and Tregal, and the susceptibility by Velvon 11 and 36Ab-1991, are definite variety characteristics.

Manitoba Co-operative Barley Test, Brandon, Man.

This test originated at the Plant Science Department, University of Manitoba, and comprised, in addition to the seven recommended varieties for Manitoba, a group of hybrids that have shown promise from a malting standpoint. Since this paper is concerned primarily with the frost reaction of named varieties, the hybrid types have not been included in the summary of results given in Table 4.

TABLE 4.—SPRING FROST INJURY TO SEVEN BARLEY VARIETIES GROWN IN THE MANITOBA CO-OPERATIVE BARLEY TEST, BRANDON, 1947

Variety	C.A. number	Per cent of foliage loss*	
		Actual	Transformed
OAC. 21	1086	13	21.0
Titan	1164	14	21.9
Vantage	1162	17	24.3
Plush	1117	17	24.3
Sanalta	1088	18	26.4
Wisconsin 38	758	24	29.3
Montcalm	1135	34	35.6

Gen. Mean—26.1 SE in %—3.80 Nec. Diff.—2.80
F value—25.39 5 per cent point—2.51

* Values given represent mean from five replicates.

While the general level of damage is lower than in the case of the other tests discussed, some highly significant differences exist. The superior frost resistance of OAC. 21 compared with that of Montcalm is strikingly brought out. The reaction of the varieties Sanalta and Wisconsin 38 may be of interest since these varieties have not appeared in previous tables.

Observations on Frost Damage to Barley Hybrids at Brandon, Man.

Frost readings were made in the case of two hybrid barley tests, totalling 130 selections. The barley in these tests had not progressed far beyond the two-leaf stage and damage appeared to be more severe than it

was in the case of the National Barley and Manitoba Co-operative Barley Tests which had been sown considerably earlier. Many of the hybrids were selections from Newal × Peatland derivatives crossed on to such varieties as OAC. 21, Mensury Ott. 60, Plush and Trebi. As might be expected, a relatively wide range of reaction was found. On the whole, however, the hybrid selections exhibited considerably more susceptibility than did the standard varieties OAC. 21, Titan and Plush. A group of Velvon selections, similar to that grown at Swift Current (*see Table 2*) proved highly susceptible. From a casual examination of the data, there appeared to be little relationship between the amount of frost damage suffered by the different hybrids and their parental make-up.

One observation is presented as a matter of interest. One group of 45 hybrids possessed a rather complicated parentage involving both OAC. 21 and Montcalm. Without exception these hybrids proved as susceptible as the Montcalm parent. On the other hand, the OAC.21 check plots could be picked out readily at some distance because of considerably less damaged foliage.

Additional Data from the Scott Station

At Scott, frost damage rates were recorded on a hybrid test in which had been included seven standard varieties. The amount of leaf loss resulting to these seven varieties was as follows: Warrior—10 per cent; Regal—22 per cent; Prospect—35 per cent; Law—38 per cent; Velvon—40 per cent; Hannchen—43 per cent; and Rex—50 per cent. The resistance shown by Warrior is noteworthy.

DISCUSSION

Consistency of Results

It is evident from an examination of the data presented that many barley varieties differed significantly in their capacity to endure freezing temperatures without injury. A feature of the results obtained was the relatively consistent reaction shown by varieties in the different tests. For example, in no instance were the varieties Montcalm, Velvon, Newal, and 36Ab. 1991 classified as anything but susceptible. On the other hand such varieties as OAC. 21, Compana and Tregal consistently fell into the resistant group. Several varieties, including Plush, Vantage and Titan, varied in their reaction from moderately resistant to resistant but in no case could they be termed susceptible.

The failure of a few varieties to react the same at Scott as they had at Brandon and Swift Current may perhaps be explained by the fact that exceptionally severe frost conditions occurred at that point. Platt (3) noted that the reactions of certain barley varieties were dependent upon the freezing temperatures to which they were exposed.

Frost Resistance in the Barley Improvement Programme

As pointed out in the introduction of this paper, spring frost resistance is not a sufficiently important character to warrant top ranking priority in any barley breeding programme. The inherent tenderness of the barley crop to low spring temperatures, however, is a challenge to barley breeders to eliminate in so far as possible yet another of the natural hazards of

barley production. There is no doubt that this character has more significance now than it did some years ago owing to a trend toward earlier seeding. In some sections of the Open Plains Area, where barley has not been a profitable crop, the barley is the first crop sown in order to benefit more fully from spring moisture. Obviously where such practices are followed, the use of varieties possessing a relatively high degree of cold resistance would be a safeguard against losses from freezing temperatures in the spring of the year.

SUMMARY

1. A report is given on the reaction of barley varieties in tests at the Dominion Experimental Stations, Swift Current, Sask., and Scott, Sask.; and at the Dominion Experimental Farm, Brandon, Man., to a severe and widespread frost occurring on the night of May 27, 1947.

2. Significant variety differences were obtained in the case of all tests.

3. The behaviour of the varieties in the different tests was generally consistent.

4. Among the more resistant named varieties were: Compana, Bay, Vance Smyrna, Munsing, Tregal, OAC. 21 and Titan. Relatively high susceptibility was shown by: Velvon, Montcalm, Flynn, Frontier, Newal and Gem.

5. The hybrid selections represented in the tests showed a wide range of reaction—from extreme susceptibility to a resistance about equal to that of OAC. 21.

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A PRELIMINARY EVALUATION OF SOME INSECTICIDES AGAINST IMMATURE STAGES OF BLACK-FLIES (DIPTERA: SIMULIIDAE)[1, 5]

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INTRODUCTION

Exploratory studies of the comparative effectiveness of various insecticides against the immature stages of blackflies were carried out at Churchill, Manitoba, in June and July, 1947, as part of a wider program of studies on the biology and control of biting flies prevalent in this region. The results of other phases of the study are to be reported elsewhere.

Apart from work with miscible oils which gave consistently uneconomic control, very little previous work has been done with insecticides against immature blackflies. In 1945, Fairchild and Barreda (3) demonstrated that a number of species of *Simulium* occurring in Guatemala could be controlled by the application of a DDT emulsion to give a concentration of 0.1 parts of DDT per million parts of water for a period of one hour, and that a solution of DDT in a turpentine-kerosene mixture and a suspension of DDT in water with a wetting agent were equally effective. Garnham and McMahon (4) have reported the local eradication of *S. neavei* Roubaud in Kenya Colony in 1946, using the much higher concentrations of 2 to more than 5 parts of DDT per million parts of water for exposure periods of 30 minutes. At these latter dosages mortality among fish and other aquatic animals was considerable. Steward (6) found that, in the laboratory, 0.25 p.p.m. DDT for one hour caused almost complete mortality of *Simulium* larvae, while Gammexane gave similar results at 0.125 p.p.m.

For purposes of comparison of these various exposure times and concentrations, it may be assumed that the time-concentration curve for any given mortality approximates to an hyperbola over the small range considered (2), and hence that:

$$\text{concentration} \times \text{time} = \text{a constant.}$$

Dosages in these experiments may then be expressed as products of concentrations in parts per million and exposure times in minutes as follows:

Fairchild and Barreda (DDT)	6	p.p.m./minutes
Garnham and McMahon (DDT)	60 to more than 150	p.p.m./minutes
Steward (DDT)	15	p.p.m./minutes
Steward (Gamma-BHC)	7.5	p.p.m./minutes

It was decided to attempt to confirm these results under the conditions at Churchill, to compare the effect obtainable with some other insecticides, and finally to explore the possibility of reducing the time of exposure required. In view of the great number of streams which would have to

[1] The results herein reported were obtained through the joint efforts of the Canadian Division of Entomology on behalf of the Defence Research Board, and the U.S. Bureau of Entomology and Plant Quarantine on behalf of the Surgeon General, Department of the Army.

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be treated for effective control in an area such as that around Churchill, the ability to do this would be of great advantage. In addition, it was hoped to obtain further data on possible toxic effects on eggs and pupae.

The work may conveniently be reported in the form of sixteen experiments, two involving aerial application of insecticides, and fourteen involving direct application of insecticides to streams. The results of these experiments are reported in the following pages. In the first two direct application experiments (Experiments 3 and 4) an attempt was made to secure quantitative estimates of populations and mortalities; this was found to be impracticable, and qualitative estimates only were attempted thereafter. The predominating species of blackfly in all experiments was *Simulium venustum* Say; species of *Eusimulium* were also involved in several of the earlier experiments. Meteorological data were recorded throughout the period of these experiments, but these data and other relevant biological information are reproduced elsewhere (8).

The following insecticidal preparations were employed in this work:

DDT (Technical Grade):

Five and 10 per cent W/V solutions in fuel oil, plus Velsicol A.R. 50 as auxiliary solvent, and 0 5 per cent Williams' red dye.

Twenty-five per cent emulsion concentrate with 65 per cent xylene and 10 per cent Triton X-100.

Fifty per cent wettable powder.

Gamma-Benzene Hexachloride:

An emulsion concentrate supplied by Canadian Industries Limited containing 5 per cent gamma isomer.

Chlorinated Camphene:

Twenty-five per cent emulsion concentrate with 65 per cent xylene and 10 per cent Triton X-100.

Chlordane:

Twenty-five per cent emulsion concentrate with 65 per cent xylene and 10 per cent Triton X-100.

Ten per cent solution in Velsicol A.R. 50 and fuel oil.

Pyrethrum—piperonyl butoxide (PPB):

Dodge and Olcott's Pyrenone emulsion concentrate (T. 143) containing 10 mgm. pyrethrins and 100 mgm. piperonyl butoxide per cc.

AERIAL SPRAYING EXPERIMENTS

Experiment 1

Two streams infested with blackfly larvae flowed in part through three plots marked out for aerial spraying trials against mosquito larvae and adults. A survey of these streams was made before the spraying to ascertain its effect on the larvae. The first of the streams flowed through the first aerial spray plot only, for a distance of about 900 yards.

The first half-mile of the second stream was in the second aerial spray plot, described under Experiment 2, the second half-mile in the third aerial spray plot, and only the last half-mile in the first aerial spray plot. Eight observation stations were marked out in the first stream, and five in the last half mile of the second; at each of these stations there was a moderate to heavy larval population on the afternoon of June 27. No pupae were present at that time. The mean depth of each stream and the rate of

FIGURE 1. Aircraft (C-47) applying DDT-fuel oil spray at Churchill.

FIGURE 2. Oil slick on stream from aerial spraying.

FIGURE 3 The treatment of Eastern Creek (Experiment 3) using a gravity dispenser Top of reservoir can be seen on the left bank

FIGURE 4 Part of the stream treated in Experiment 4 some days before treatment

flow were estimated at the same time, the latter by timing a surface float over a measured distance with a stop-watch to get the maximum speed, and calculating the total flow from the formula:

$$V_a = 2/3 \,.\, V_m \text{ (approx.)}$$

and

$$\text{Flow} = V_a \,.\, A$$

where V_m is the measured maximum speed, V_a the average speed and A the cross sectional area of the water channel. Suitably uniform sections of each stream were selected for measurement, and a number of timings taken.

Spraying (Figure 1) was carried out on the evening of June 27 from a C-47 aircraft (R.C.A.F.) equipped with cargo tanks and a vertical gravity flow discharge pipe extending below the fuselage. The temperature of the water at this time was 58° F. The material used was a 5 per cent solution of DDT in fuel oil and this was put down at a mean concentration of 0.26 lb. DDT per acre. The population of blackfly larvae was re-checked on June 28, July 21 and August 7. No living eggs, larvae, or pupae of any species of blackfly were found in the treated length of the first stream at any of these examinations. Untreated portions of the stream, and similar untreated streams in the same vicinity continued to harbour immature stages until at least August 7. In the treated length of the second stream, the only larvae found at the examination on June 28 were at station 5, where there were two or three half-grown larvae per plant, on grasses rooted in the centre of the stream. This station was very near to the upstream limit of the treated length, so that the exposure time was very short indeed, and the insecticide probably not well distributed. At the later examinations, which were made after the upper reaches of the stream had been treated as well, no living eggs, larvae, or pupae were found.

The results of these observations are summarized in Table 1. DDT concentration was estimated on the assumption that all the material falling on the surface of the stream was carried along in it, as follows:

Concentration in parts per million:

$$\frac{\text{Deposit lb. per acre} \times 10^6}{4840 \times 9 \times \text{mean depth in feet} \times 62.5}$$

In the range of exposure time given, the minimum time represents the theoretical time for the water which received the spray to flow past the highest upstream observation station; the maximum time relates likewise to the furthest downstream station. In stream 1 the highest station was about half way between the limits of the sprayed length, so that here the minimum exposure time was quite high.

Experiment 2

The second aerial spray plot covered half a mile of stream No. 2 from the source downwards. This was examined for blackfly larvae on the morning of June 30 immediately before the spraying, when 4 stations, each with a heavy to very heavy larval population were marked out. The

TABLE 1.—SUMMARY OF DATA FROM INSECTICIDAL TREATMENT OF STREAMS

Exp. No.	Date of treatment	Observed treated length of stream (yards)	Average flow in Cusecs	Insecticide formulation	Method of application	Concentration p.p.m.	Application time (minutes)	Dosage* (p.p.m./min.)	Larval population: Before treatment	Larval population: Twenty-four hours after treatment	Larval population: Subsequently
1	June 27	900	12.20	5% DDT in fuel oil	Aerial spray	0.095	15 to 30	1.425 to 2.85	Heavy	Nil	Nil for at least 41 days
2	June 30	2500	10.00	5% DDT in fuel oil	Aerial spray	0.150	0 to 60	0 to 9.00	Heavy	Nil	Nil for at least 41 days
3	July 11	1400	88.00	10% DDT in fuel oil	Gravity dispenser	0.100	30	3.00	Heavy all stages	Nil	Reinfested with young larvae in 14 days
4	July 11	850	6.70	10% DDT in fuel oil	Hand sprayer	0.100	30	3.00	Moderate	Nil	Reinfested with all stages in 14 days
5	July 14	250	0.57	10% DDT in fuel oil	Medicine dropper	0.590	15	8.85	Heavy and mature	Nil after first 100 yd.	—
6	July 14	85	1.98	Fuel oil	Medicine dropper	1.680	15	25.20	Heavy all stages	Almost unchanged	—
7	July 14	300	6.30	10% chlordane in fuel oil	Medicine dropper	0.079	15	1.185	Heavy all stages	Some control for 100 yd.	Remained infested
8	July 14	600	120.00	50% DDT wettable powder	Portable press sprayer	0.075	20	1.50	Very heavy	Few first 350 yd., nil beyond	—
9	July 14	400	1.97	10% DDT in fuel oil	Medicine dropper	0.126	5	0.63	Heavy all stages	Slight reduction	Remained infested
10	July 15	4400	270.00	10% DDT in fuel oil	Two pressure sprayers	0.176	15	2.64	Very heavy	Nil after first 100 yd.	—
11	July 18	250	0.57	25% DDT emulsion	Medicine dropper	0.490	15	7.35	Heavy	One living larva found	—
12	July 20	80	0.87	5% gamma-BHC emulsion	Graduate and paddle	0.100	15	1.50	Very heavy and mature	About 50% reduction	Remained infested
13	July 21	650	0.54	P.P.B. (Pyrenone) emulsion T.143	Graduate and paddle	0.500	15	7.50	Moderate and mature	Reduced for 150 yd. only	Remained infested
14	July 21	1500	1.62	25% DDT emulsion	Graduate and paddle	0.100	15	1.50	Moderate all stages	Nil	Nil for at least 10 days
15	July 24	20 120	8.20 17.50	5% gamma-BHC emulsion	Graduate and paddle	0.190 0.089	15	2.85 and 1.335	Heavy Heavy	Few living About half	Remained infested Remained infested
16	July 24	100	13.60	25% chlorinated camphene emulsion	Graduate	0.164	15	2.46	Very heavy	No change	Remained infested

* See explanation in Introduction.

temperature of the stream water was 55° F. The same insecticidal material was used in the aerial spraying of this plot, but the deposit was 0.48 lb. DDT per acre. The stream was re-examined on the same afternoon about three hours after the end of the spraying. Only a few sick-looking larvae were found, less than 1 per cent of the previous population, all of them near the origin of the streams in a poorly defined area largely under water. Many of these were hanging on silk. A further examination on the morning of July 1, water temperature 54° F., disclosed no living larvae, either in the treated stretch or below this. Subsequent examinations were made on the same dates as for stream No. 1 and with the same results.

The third aerial spraying operation, on the morning of July 3, put down a deposit of 0.26 lb. DDT per acre on the half mile stretch of stream No. 2 in between the portions treated in the first and second operations. As this stretch had been found to be without larvae two days previously, no further observations were made on it at that time. In later surveys of the stream, this stretch was found to be equally free of infestation.

DIRECT APPLICATION EXPERIMENTS

Experiments 3-16

It had been intended to conduct these experiments primarily with emulsion formulations, but in view of the results obtained in the aerial spraying experiments with cheaper and more readily obtained oil solutions, it was decided to use these and to employ emulsions only for comparison.

The first step was the selection of suitable streams. The requirements were a high population of blackfly larvae, a well defined channel presenting a reasonable length with a minimum of tributaries or distributaries, and suitable localities for flow measurement (as described in the section on the aerial spraying experiments) and insecticide application. The streams were then surveyed, the amount of material needed to give the required concentration and time of exposure calculated approximately, and the application made. Usually an observer was present in the stream during the treatment, to watch the progress of the insecticide down the stream and observe any immediate reactions of the blackfly larvae. In general, the insecticide was applied a short distance below the upstream end of the surveyed length, in order to leave a portion of the stream undisturbed for check observations. The stream was then resurveyed as nearly as possible 24 hours after the treatment and, in most experiments, again when opportunity offered after another interval of about a week or more.

Fourteen streams were treated in all, using various concentrations and exposure periods, and including at least one test of each of the five insecticides listed in the introduction. The data and results are summarized in Table 1.

The data presented in Table 1 show that DDT in fuel oil, as a wettable powder suspension, and in emulsion form gave good control of blackfly larvae at a minimum dosage of 1.5 p.p.m./min., or 1 : 10,000,000 applied for a period of 15 minutes. Fuel oil alone at 25.2 p.p.m./min., or 1 : 600,000 for 15 minutes was ineffective. Gamma-BHC, as an emulsion, at 1.5 p.p.m./min., or 1 : 10,000,000 for 15 minutes, gave about 50 per cent

control; at approximately double this dosage a high percentage reduction of infestation was obtained. Chlordane, in fuel oil, at 1.185 p.p.m./min., or 1 : 12,700,000 for 15 minutes, gave partial control for a short distance from the point of application. Chlorinated camphene, as an emulsion, was ineffective at 2.46 p.p.m./min., or 1 : 6,000,000 for 15 minutes.

Eggs of *S. venustum* appeared to be unaffected by DDT in fuel oil at a dosage of 3 p.p.m./min., or 1 : 10,000,000 for 30 minutes. This was indicated in Experiment 4, when eggs hatched uniformly from treated and untreated parts of the stream.

Pupae in treated streams also showed no obvious ill effects from the insecticide applications, except in the case of gamma-BHC. This was ascertained by the percentage emergence of adults from samples of pupae taken from treated and untreated portions of the streams. In Experiment 12 where a dosage of gamma-BHC of 1.5 p.p.m./min., or 1 : 10,000,000 for 15 minutes, was used, emergence from treated pupae of *S. venustum* was only 12 per cent as compared with 82 per cent from untreated ones.

ADDITIONAL NOTES ON EXPERIMENTS

Description of Treated Streams

Experiments 3, 15, and 16 were carried out in different parts of Eastern Creek and its tributaries. This is a substantial stream about five miles east of Churchill camp, flowing northward into Hudson Bay through tundra meadow and patches of dwarf birch and willow, from its source in an extensive area of lakes about three miles inland. Heavy infestations of larvae were present on stones and submerged vegetation when the treatments were made. A water sample taken on July 10 had a pH of 8.46; the salinity was 56 p.p.m. chlorides measured as sodium chloride. In addition to the predominant *Simulium venustum*, two species of *Eusimulium* were in the pupal form and emerging when Experiment 3 was carried out (July 11). On the occasion of Experiments 15 and 16 (July 24) the infestation was entirely of larvae.

Experiments 1, 2, 4, 7, 12, 13, and 14 were made in small streams all, except 4 and 7, flowing in a general westerly direction to the Churchill River. Number 4 (Figure 4) originates in a small lake on the tundra and flows into Hudson Bay east of Churchill, and Number 7 flows from Warkworth Creek into the Goose River. The bottoms of the streams generally contained sand, gravel, stones and boulders. Infestations ranged from moderate to very heavy. A water sample from stream 4 had a pH of 8.35 and a salinity of 143 p.p.m.

Experiments 5, 6, 9, and 11 were in drainage ditches, similar to the type shown in Figures 6 and 10. The turbulence in these channels was less than in the streams, being almost nil at the time of treatment. However, in spite of the slow rate of flow, parts of them were heavily infested with larvae and pupae of *S. venustum*.

Experiment 8 was in the Goose River, a short distance downstream from the railway bridge which crosses it. This is a large stream (Figure 7) with a bottom of large stones and boulders. Experiment 10 was carried

FIGURE 5. Stream treatment with a hand spray pump in Experiment 4

FIGURE 6. Drainage channel typical of those treated in Experiments 5, 6, 9, 11 and 14

FIGURE 7. General view of Goose River, treated in Experiment 8.

FIGURE 8. General view of Warkworth Creek, treated in Experiment 10.

out in Warkworth Creek, the largest river treated (Figure 8). Large stones and boulders cover its bottom. Blackfly larvae and pupae were abundant in both of these rivers at the time of treatment.

The temperature of the water in the various streams at time of treatment ranged from 55° F. in Experiment 2, to 63° F. in Experiment 15.

Flow Measurement

The method of flow measurement employed in all but one experiment was as described under Experiment 1 (Aerial Spraying Experiments). The exception was Experiment 10, in which, because of the size of the Warkworth Creek (Figure 8), a somewhat more accurate method was used. This involved the application of Simpson's rule, using the bridge piers as ordinates. Depth was measured at either side of each of the five piers and the flow determined by the float method, two readings being taken at the mid-line of each of the six channels between the banks and the piers.

Methods of Application

The gravity dispenser used in Experiment 3 was contrived by C. N. Husman. It consisted of a 4-gal. drum fitted with a wheel valve laterally near the bottom, leading through five feet of $\frac{3}{8}$-inch bore rubber tubing to a four-foot length of $\frac{3}{8}$-inch bore copper pipe. This was arranged as shown in Figure 3, with the container previously calibrated for discharge rate on the bank of the stream, and the outlet of the copper pipe held in a wooden support 2-3 inches above the water surface.

The use of the hand sprayer in Experiment 4 is illustrated in Figure 5. During the first half of the treatment the material was sprayed on to the surface of the stream, with the jet held a few inches above the surface. Some of the finer mist was carried away by the high wind, so during the remainder of the application the jet was held under water. This method appeared quite satisfactory.

In Experiments 5, 6, 7, 9, and 11, the quantities used were so small that application over the required period was made by medicine dropper timed by stop watch. In Experiments 12-15, the water was agitated with a paddle as the insecticide was dribbled in, to ensure quick and uniform distribution. Portable pressure sprayers were used in Experiments 8 and 10 as these involved the treatment of rather large streams (Goose River and Warkworth Creek). The streams were crossed and recrossed by the operator, or operators, as the material was sprayed on.

EFFECTS OF TREATMENTS ON OTHER ANIMAL LIFE IN STREAMS

Effect of Application of DDT by Aeroplane

In Experiment 2, scum consisting of insects, spray material, and debris which had accumulated on vegetation at the margins of the stream in the second aerial spray plot was collected in water on the afternoon of the spraying and preserved in alcohol. Detailed examination of this material was carried out at Edmonton in August, 1947, when its condition was

found to be such that identifications of most insects beyond the family were not practicable. The groups of insects and other arthropods represented,** with the number of specimens of each, are as follows:

Other Arthropods:	
Araneae	23
Acarina	
Hydracaridae	13
Insects:	
Apterygota	
Collembola	
Arthropleona (3 spp.)	223
Symphypleona	448
Exopterygota	
Plecoptera	
Nemouridae	
Nemoura spp. nymphs	37
adults	91
Thysanoptera	
Thripidae	8
Homoptera	
Aphidae	1
Charmidae nymphs	5
adults	2
Coccidae	
*Steingelia**, n. sp.	10
Endopterygota	
Coleoptera	
Carabidae	3
Elateridae	3
Dytiscidae larvae	2
adults	4
Chrysomelidae	2
Hydroscaphiidae	6
Trichoptera	
Limnophilidae	1

* Det. by H. Morrison, U.S. Bur. Ent. & Plant Quar., Washington, D.C.

Diptera	
Nematocera	
Culicidae	
Aedes spp. males	2
females	8
Chironomidae pupae	7
adults	1504
Chironomidae	
Ceratopogonidae	16
Simulidae larvae	43
adults	3
Mycetophilidae	53
Cecidomyidae	9
Scatopsidae	5
Brachycera	
Dolichopodidae	1
Empidae	13
Cyclorrhapha	
Lonchopteridae	2
Cordyluridae	2
Syrphidae	6
Phoridae	8
Chloropidae	5
Anthomyidae	4
Hymenoptera	
Chalastogastra	
Tenthredinidae	3
Cimbicidae	1
Clistogastra	
Ichneumonidae	2
Mymaridae	6
Proctotrupidae	4
Chalcidae	6
Cynipidae	2

This represents a total of some 2600 specimens belonging to 37 different families, of which only 56 specimens (representing 2 families) belong to species it was desired to control. Of the remainder, many are parasites and predators. Although this was clearly not a strictly random sample, it serves to indicate how insignificant the objective result of such an operation may be in comparison with its total effect on the biocoenotic equilibrium.

Effect of Application of DDT by Hand

In Experiments 3 and 4, wire screens, 3 × 4 feet in size, and 16 mesh to the inch, were fastened in the streams before treatment (DDT 1 : 10,000,000 for 30 minutes) to secure samples of animal life presumably killed by the treatments. Twenty-four hours after treatment the screens were removed and the material collected on them preserved. The quantity of vegetable and inorganic debris mixed in with the specimens in these

** Grateful acknowledgment is made of assistance received from R. B. Miller, E. Moore, and E. H. Strickland, of the University of Alberta, in the identification of material taken in the treated streams.

FIGURE 9 Treatment site of the stream treated in Experiment 12

FIGURE 10 Drainage channel portion of the stream treated in Experiment 14

EXPERIMENT II

Methods and Materials

Three portions of a sample of hexane extracted linseed oil meal were soaked in four times the amount of water at room temperature for ten hours and dried at room temperature, 60-70 degrees C. and 90-100 degrees C., respectively. The original and treated meals were added at about 20 per cent level on a protein equivalent basis to the basal ration used in the previous experiment. The crude protein content of the rations were equalised by adjusting the amounts of corn. Results of the feeding trial using 15 chicks per lot for a four-week period are given in Table 2.

Results and Discussion

From Table 2 it is seen that drying the water incubated meal at 90-100 degrees C. gave a product significantly better than all the others. The improvements which resulted from the lower drying temperatures, however, did not quite reach the significance level. The mortality in these two lots and in the lot which received the untreated meal was rather high. This might indicate that there is a larger residual toxicity in the meals prepared at lower drying temperatures. In contrast with the results in this experiment, Kratzer (2) observed significant improvement in the meal by incubation with water followed by drying at room temperature. This difference might be due to the fact that he used a higher level (35 per cent) of the meal and the rations contained little or no animal protein, whereas 5 per cent of animal protein supplements was used in this experiment. It would thus appear that, apart from the improvement brought about by the action of water during the soaking period, the temperature of drying is a factor which affects the degree of improvement. Within limits, a higher drying temperature may be expected to give a better product.

TABLE 2.—EFFECT OF DRYING TEMPERATURE ON THE FEEDING VALUE OF WATER TREATED LINSEED OIL MEAL

Lot	Description of linseed oil meal	Initial body weight, gm.	Final body weight, gm.	Mortality per cent	Significance levels* Lots: 1	2	3
1	Untreated	60.5	132.6	33.3	—	—	—
2	Incubated with water, dried at room temperature	60.6	160.6	20.0	0.07	—	—
3	Incubated with water, dried at 60-70 degrees C.	60.5	163.3	33.3	0.06	—	—
4	Incubated with water, dried at 90-100 degrees C.	60.0	194.1	6.7	0.01	0.02	0.05

* The significance level of differences between final weights in any two lots is obtained by cross reference. The value for lots 2 and 4 is thus 0.02.

EXPERIMENT III

Methods and Materials

An aqueous solution of flaxseed mucilage was prepared as in Experiment I and divided into four parts. One portion was kept at room temperature for 24 hours, a second portion was autoclaved for 15 minutes at 250 degrees F., cooled and brought back to original weight with water, a third portion was dried in the oven at 80 degrees C., water added to redissolve the mucilage and brought back to original weight with water. The fourth portion was used immediately as control. The viscosity of these liquids was compared by noting the time of flow of a definite volume of the liquid under similar conditions through a vertically fixed tube of narrow and uniform bore. Results are given in Table 3.

Results and Discussion

It is seen from Table 3 that the time of flow and hence the viscosity of the mucilage is lowered by all the treatments, particularly by autoclaving and by drying. This effect may arise through changes in the colloidal nature of the solution. Water treatment of linseed oil meal with subsequent drying would therefore be expected to cause similar changes in the mucilage of linseed oil meal. In a similar way this may account for the varying degrees of improvement observed in the feeding trial in Experiment II.

TABLE 3.—VISCOSITY CHANGES IN AN AQUEOUS SOLUTION OF FLAXSEED MUCILAGE

No.	Sample	Time of flow in seconds
1	Untreated	915
2	Kept at room temperature for 24 hours	485
3	Autoclaved	122
4	Dried at 80° C. and redissolved	179

SUMMARY AND CONCLUSIONS

1. Flaxseed mucilage when incorporated into a starter ration containing 15 per cent soybean meal has a significant growth depressing effect on chicks and causes the development of beak necrosis.

2. In the improvement of linseed oil meal by water treatment, higher drying temperature has a greater beneficial effect.

3. The viscosity of aqueous solutions of flaxseed mucilage is appreciably reduced by autoclaving and by drying at 80 degrees C., and to a lesser extent by holding at room temperature for 24 hours.

4. It is suggested that the presence of the mucilage in linseed oil meal is one of the factors involved in its low feeding value for the chick and that the improvement in the meal as a result of higher drying temperatures in the water treatment process is partly due to alteration in physical properties, notably viscosity, of the mucilage.

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CYANOGENETIC GLUCOSIDES AND TRYPSIN INHIBITORS IN LINSEED OIL MEAL[1]

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Many workers have reported that linseed oil meal gives unsatisfactory results when used at levels over 5 per cent in chick starter rations (1), (5), (11), (12). Even after correcting amino acid deficiencies in the meal by adequate supplementation it caused significant growth depression in chicks (9). When it was used at 30 per cent levels in the ration high mortality and intestinal disorder were observed (3). These results have been taken as indicative of the presence of certain toxic factors in the meal. There is some evidence that linseed oil meal in the ration depresses the availability of some of the B-complex vitamins (6). It is believed also that other factors might be involved, namely, cyanogenetic glucosides and trypsin inhibitors. The presence of these factors in some vegetable feedstuffs is known to cause unsatisfactory results under certain conditions of feeding practice.

Flaxseed contains a glucoside which under favourable conditions of warmth and moisture liberates prussic acid by the action of an enzyme present in the seed (10). However, no specific instance of prussic acid poisoning has been reported in poultry. Ordinarily, the heat to which the ground seed is subjected during the oil expressing process inactivates or destroys the enzyme. Also, the addition to chick rations of potassium cyanide in amounts equivalent to the prussic acid content in some linseed oil meal samples did not lead to any poisoning effect.* It is possible, however, that different samples of the meal differ in the extent to which they liberate prussic acid.

The presence and properties of trypsin inhibiting factors have been extensively studied in the case of soybean (7), (8) (13), (14). These factors interfere with the normal action of tryptic enzymes in the digestive system and in this way depress the utilisation of the protein in the food. It would appear to be fairly well established that their presence partly accounts for the unsatisfactory feeding value of raw soybean for chicks. In view of the above reports it was felt that the possible implication of these two toxic factors should be more fully investigated in linseed oil meal.

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[1] Contribution from the Faculty of Agriculture of McGill University, Macdonald College, Que., Canada. Macdonald College Journal Series No. 243.

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NOTES ON SOME OF THE NEWER ACARICIDES[1]

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The following brief discussions on some of the newer acaricides used for the control of two-spotted mite, *Tetranychus bimaculatus* Harvey and European red mite, *Paratetranychus pilosus* (C. & F.), are based largely on the greenhouse and insectary experiments described by the junior author in two processed reports published by the Dominion Department of Agriculture: *Report on Acaricide Investigations, 1947, Part 1,* issued June 1947; *Part II,* issued December 1947. Unfortunately, the very necessary information about these new materials, which can be obtained only from several years' experience with them in the field under a variety of conditions, is still lacking.

DI-PARA-CHLOROPHENYLMETHYLCARBINOL (DMC)

In greenhouse experiments, DMC at 0.25 lb. per 100 gal. in the form of a 50 per cent spray powder destroyed all active stages and 99 per cent of the eggs of the two-spotted mite. Against European red mite, the mortality two weeks after application was consistently 96 to 100 per cent, the residue remaining highly effective for the two-week period. Both the spray powder and an emulsifiable solution gave very similar results.

DMC was found to be compatible with elemental sulphur, lead arsenate, ferric dimethyl dithiocarbamate, two different fixed copper fungicides, nicotine sulphate, DDT and benzene hexachloride. Hydrated lime and bordeaux mixture slowed down the rate of kill but the ultimate mortality was not affected.

No foliage injury was produced in the greenhouse on bean, tomato, cucumber, roses, apple or plum.

In field experiments DMC gave good results in British Columbia and Washington.

It appears to be specifically an acaricide, having no appreciable insecticidal action on codling moth, aphids, mealy bug and several other greenhouse insects on which it was tried.

No information is on hand regarding its availability and cost, although it is now being advertised under a trade name.

DI-(PARA-CHLOROPHENOXY)METHANE (DCPM)

Used as a 40 per cent micronized spray powder, 1 lb. actual DCPM per 100 gal. was almost 100 per cent effective against both active stages and eggs of the two-spotted mite. This material also has remarkable residual properties against all stages for about a week. Adult mites placed on sprayed plants laid large numbers of eggs before succumbing, but the outstanding residual toxicity of DCPM destroyed nearly 100 per cent of the eggs and young during the first week.

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DCPM is also very effective against the European red mite. In a series of tests it was observed that practically 100 per cent of the population had been destroyed two weeks after spraying with 1 lb. per 100 gal., as a result of the unusual residual and ovicidal effect. At 0.5 lb. per 100 gal., the kill was still over 99 per cent after 14 days, and at 0.25 lb. it was 88 per cent.

DCPM is compatible with all the common spray materials, including hydrated lime and bordeaux.

In one year's field trials against European red mite on apple, plum and peach, DCPM gave quite satisfactory results, although these were not quite so outstanding as in the greenhouse experiments.

In both the greenhouse and orchard experiments, DCPM caused no injury to apple, plum, peach or bean, but stunted cucumbers. Unfortunately, elsewhere it has caused russetting of apples and pears.

With the hope of obviating russetting, investigations are now under way with combinations of low concentrations of DCPM and dinitro-o-cyclohexylphenol (40 per cent spray powder). Preliminary tests indicate that 4.8 oz. DCPM and 1.2 oz. actual DNOCHP, per 100 gal., give good initial kills followed by excellent residual action.

DCPM appears to have relatively low toxicity to higher animals.

PARATHION

Parathion proved to be very effective against the two-spotted mite even when used at 0.15 oz. per 100 gal., destroying 98 per cent of the active forms immediately and 78 per cent after 16 days. However, in order to obtain the full residual value of the material, it was necessary to increase the concentration to 0.6 oz. Comparable results were obtained against European red mite under greenhouse conditions. At high concentrations parathion has pronounced ovicidal action which is profoundly affected by temperature. For example, at 4.8 oz. per 100 gal. the percentage kill of eggs of two-spotted mite at an average temperature of 80.5° F. was 98.2 per cent; at 66.6°, 24.3 per cent; and at 59.6°, 14.8 per cent. The ovicidal effect of low concentrations, e.g. 0.6 oz., is apparently slight, even at high temperatures, and the efficiency of parathion at these rates is dependent on its residual effect on newly-hatched young.

Parathion is compatible with all commonly used spray materials except bordeaux, which, while apparently not greatly affecting the immediate toxicity of the compound, lowers its residual toxicity appreciably. Strangely enough, it is compatible with hydrated lime; parathion-lime spray mixtures allowed to stand 24 hours before use retained their full effectiveness.

Because of its high mammalian toxicity, the future of this material as an acaricide and insecticide now rests in the hands of the toxicologists.

TETRAETHYL PYROPHOSPHATE (TEPP)

Tetraethyl pyrophosphate, including so-called 'hexaethyl tetraphosphate', in which the former is the principal ingredient, is very effective against the active stages of mites, but has no appreciable ovicidal or

residual value, and for this reason the timing of spray applications may be too critical in practical mite control. Uncertainty regarding the actual TEPP content of the experimental materials has been a handicap in all work with this compound.

Recent experiments have demonstrated that a combination of the monoethanolamine salt of DNOCHP and TEPP has outstanding ovicidal value, e.g. mono DNOCHP at 4 oz. actual DNOCHP plus 0.5 pint 'technically pure HETP' per 100 gal. destroyed 98.4 per cent of the eggs of two-spotted mite; mono DNOCHP alone, 19.7 per cent; HETP alone, 4.8 per cent. This may have little practical significance because of cost and also because the combinations may injure foliage of bean and apple.

MONOETHANOLAMINE, TRIETHANOLAMINE AND AMMONIUM SALTS OF DINITRO-O-CYCLOHEXYLPHENOL

These salts were prepared just before use by adding an excess of the respective base to either finely-powdered technical DNOCHP or 40 per cent DNOCHP spray powder. Both forms of DNOCHP were equally satisfactory.

In the greenhouse, all three salts at 2.5 oz. actual DNOCHP per 100 gal. initially destroyed from 94 to 100 per cent of the active forms of European red mite, and examination of the infested plants 14 days after spraying showed a practically complete clean-up by residual action. The salts are not compatible with hydrated lime, bordeaux or certain fixed copper fungicides, and lead arsenate reduces their effectiveness to some extent. They can be used with ferric dimethyl dithiocarbamate, elemental sulphur and some fixed coppers.

In field trials in 1947, promising results were obtained, 2 oz. DNOCHP per 100 gal. being sufficient to give reasonable control of orchard mites in British Columbia, whereas 4 oz. were required in Ontario. In the absence of better materials in commercial quantity, the mono salt is being recommended for growers' use in 1948.

Under greenhouse conditions slight injury was produced on apple foliage, but the salts appear safe in the field. In Ontario they proved to be unsafe on peach, but in British Columbia they caused no injury.

DICYCLOHEXYLAMINE SALT OF DINITRO-O-CYCLOHEXYLPHENOL (DN-111)

Even under greenhouse conditions, DN-111 has given very erratic results. For instance, in the 1946 greenhouse tests against two-spotted mite, the kill at 1.5 lb. per 100 gal. varied from 22.6 to 99.6 per cent, whereas the results from the ammonium salt at approximately equivalent DNOCHP concentrations were remarkably consistent, varying from 93 to 100 per cent.

Field trials with DN-111 in different provinces have also given erratic and generally unsatisfactory results against Europen red mite on apple. On peach, it has usually been very effective in Ontario.

UNCOMBINED DINITRO-O-CYCLOHEXYLPHENOL

In greenhouse experiments, a 40 per cent DNOCHP spray powder (*DN Dry Mix No. 1*) has given better results, on the whole, than any of the salts, against both the two-spotted mite and the European red mite. At 1.2 oz. actual DNOCHP per 100 gal., it destroyed 98 per cent of European red mite after 14 days, as a result of both immediate and residual toxicity. Where two-spotted mites were placed daily on plants sprayed with 5 oz. DNOCHP per 100 gal., the residue continued to be effective for 10 days, killing 80 to 100 per cent of the introduced mites. In contrast, the monoethanolamine salt at equivalent DNOCHP concentrations at the end of 3 days killed 69.8 per cent, and after 7 days only 26 per cent.

At 5 oz. actual DNOCHP per 100 gal., the 40 per cent spray powder produced no injury on apple or bean. On the other hand, finely-powdered technical DNOCHP at the same rate caused extremely severe injury.

LAURYL-2-THIAZOLINYL SULPHIDE

A formulation supplied under the code number IN-4200, at a dilution of 1-800, destroyed 100 per cent of the active stages of two-spotted mite and 98.6 per cent of European red mite. It also killed 91 to 99 per cent of two-spotted mite eggs, and the residual action remained high for approximately 6 days under greenhouse conditions. It appears compatible with most common spray materials, although both hydrated lime and bordeaux slightly reduced the ovicidal action.

Foliage injury, mostly of a minor character, appeared on some of the sprayed plants, including bean and plum; a single series of tests on peach did not produce any injury.

CHLORINATED CAMPHENE

In the greenhouse, chlorinated camphene had considerable acaricide value at high rates, e.g. 1 to 4 lb. per 100 gal. There was little ovicidal action but the residue effectively destroyed the young of two-spotted mite hatching after spraying.

Orchard tests in British Columbia showed this material to be fairly effective against European red mite.

SUMMER OIL

Under conditions where it can be used, 1 per cent summer oil emulsion has proved remarkably efficient over many years. Its chief limitation is its incompatibility with sulphur or DDT. It should be stressed that the summer oil used in Ontario is relatively heavy, with a viscosity of approximately 80 seconds Saybolt at 100° F. and an U.R. of 95 per cent. Quite extensive field experiments with oils of lower viscosity (45 secs. Say.) have shown them to be much inferior as acaricides.

SUMMARY

This paper presents brief notes on the effectiveness and limitations of newer acaricides against European red mite and two-spotted spider mite, based on greenhouse and orchard experiments in Canada. Di-para-chlorophenylmethylcarbinol was one of the best of the specific acaricides. Di-(p-chlorophenoxyl)methane was also quite effective and did not injure fruit in limited experiments in Ontario. Parathion was outstanding in greenhouse trials even at very low concentrations. Tetraethyl pyrophosphate lacked residual and ovicidal effects and its value in orchards is doubtful. The grower-prepared monoethanolamine salt of dinitro-o-cyclohexylphenol (DNOCHP) is being extensively used with good results in British Columbia. The proprietary dicyclohexylamine salt of DNOCHP has given very erratic and often unsatisfactory results. Uncombined DNOCHP was a good acaricide but there may be danger of foliage injury. Lauryl-2-thiazolinyl sulphide was promising in preliminary tests. Chlorinated camphene was fairly effective. Summer oil emulsion remains one of the best acaricides but is incompatible with sulphur or DDT.

All acaricides tested possessed limitations of varying degree.

FLAXSEED MUCILAGE AND ITS EFFECT ON THE FEEDING VALUE OF LINSEED OIL MEAL IN CHICK RATIONS[1]

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In contrast with most of the common sources of plant protein supplements, flaxseed has a characteristically high mucilage content. In earlier work 6.3 parts of mucilage were obtained from 100 parts of flaxseed (8). This work also showed that the mucilage was not attacked by the enzymes in dried pancreas and that when fed to guinea pigs and rats about 75 per cent was excreted unchanged. Recent work has indicated that it is the salt of a polymerised aldotetronic acid (1), (9). It is stated that by virtue of its capacity to absorb water the mucilage contributes to the regularity of the digestive system in large animals and hence accounts for the beneficial effects of linseed oil meal in live stock rations (7). In poultry rations, however, the laxative effect due presumably to the presence of the mucilage might become harmful when they contain 4 to 5 per cent of linseed oil meal (10). At higher levels, this effect should become more pronounced. Also, the high viscosity of aqueous solutions of the mucilage causes the ration to become sticky and leads to the development of beak necrosis and deformity. This is a characteristic symptom in chicks fed large amounts of linseed oil meal and could be one reason for the reduced feed intake and poor growth. If on the other hand the digestibility of the mucilage in chicks is low, as in the case in rats, the presence of this viscous and relatively indigestible material in the small intestine might interfere with the normal processes of digestion and absorption. It was thought that this specific detrimental effect of the mucilage could be tested by feeding a standard ration containing added mucilage.

Many workers have found that the feeding quality of linseed oil meal is improved by a process of water treatment with and without subsequent drying of the moistened meal (2), (3), (4), (5), (6). Various drying temperatures have been used but it has not been reported whether or not the drying temperature has any specific effect. The present work was undertaken to study this effect and also the effect of these various treatments on the viscosity of the mucilage. If the mucilage content of linseed oil meal influences the feeding value of the latter it may be expected that any treatment which affects the feeding value of the linseed oil meal would also alter the physical characteristics of the mucilage.

EXPERIMENT I

Methods and Materials

An aqueous solution of the mucilage was prepared by soaking flaxseed in four times its weight of water at room temperature for 24 hours and centrifuging. The mucilage was precipitated by pouring the above extract

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into twice its volume of 90 per cent alcohol, washed with a little absolute alcohol, air dried and then ground finely. Analysis gave 11.5 per cent protein as calculated from total nitrogen by the Kjeldahl method. This evidently was a water soluble impurity carried over from the flaxseed but further purification was not attempted. The product was added at 2 per cent level to a standard starter ration. This ration was prepared by adding 5 lb. yellow corn and 15 lb. soybean meal to a basal ration of the following composition: Ground yellow corn 13 lb.; ground wheat 20 lb.; ground barley 20 lb.; ground oats 13 lb.; buttermilk powder 2 lb.; fish meal (65 per cent protein) 1 lb.; meat meal (50 per cent protein) 2 lb.; alfalfa meal 5 lb.; dried brewer's yeast 1 lb.; ground limestone 2 lb.; iodised salt 1 lb.; fortified fish oil (1850 A—400D_3) 200 gm.; manganese sulphate 6 gm., and riboflavin 0.1 gm. On the basis that flaxseed contains about 6.5 per cent of mucilage and 35 per cent of oil and that the prepared mucilage contains about 10 per cent of protein matter as impurity the above addition would be equivalent to an inclusion of 18 per cent linseed oil meal in terms of mucilage content. The original starter ration before and after admixture with mucilage was fed for a 5 weeks' period using 15 chicks per lot. Results are given in Table 1.

TABLE 1.—EFFECT OF ADDING FLAXSEED MUCILAGE TO A STANDARD CHICK STARTER RATION

Lot	Mucilage added to ration	Initial body weight, gm.	Final body weight, gm.	Feed gain ratio
1	Nil	58 8	305.8	2.7
2	2 per cent	58.5	224.9*	3.5

* The difference between final weights in the two lots is highly significant.

Results and Discussion

From Table 1 it is seen that the addition of mucilage depressed the feeding value of the ration when measured by gain in body weight and efficiency of feed utilisation. Almost all the birds in the lot receiving the mucilage ration had beak necrosis and many had crooked beaks and ruffled feather coats which are characteristic symptoms of feeding high levels of linseed oil meal. The lessened feed intake which was in part due to the beak defects would be one reason for the poor growth. But the feed: gain ratio indicates that the presence of the mucilage also depressed the utilisation of the feed actually consumed. Some of the factors responsible for the low feeding value of linseed oil meal would thus appear to be present in the mucilage portion. It is possible that aqueous extraction and precipitation with alcohol brought about some alteration in the nature of the mucilage and that in its native state its effect would be different. It is also possible that the protein material carried over in the mucilage preparation contained some specific toxic constituent present in the flaxseed.

EXPERIMENT II

Methods and Materials

Three portions of a sample of hexane extracted linseed oil meal were soaked in four times the amount of water at room temperature for ten hours and dried at room temperature, 60-70 degrees C. and 90-100 degrees C., respectively. The original and treated meals were added at about 20 per cent level on a protein equivalent basis to the basal ration used in the previous experiment. The crude protein content of the rations were equalised by adjusting the amounts of corn. Results of the feeding trial using 15 chicks per lot for a four-week period are given in Table 2.

Results and Discussion

From Table 2 it is seen that drying the water incubated meal at 90-100 degrees C. gave a product significantly better than all the others. The improvements which resulted from the lower drying temperatures, however, did not quite reach the significance level. The mortality in these two lots and in the lot which received the untreated meal was rather high. This might indicate that there is a larger residual toxicity in the meals prepared at lower drying temperatures. In contrast with the results in this experiment, Kratzer (2) observed significant improvement in the meal by incubation with water followed by drying at room temperature. This difference might be due to the fact that he used a higher level (35 per cent) of the meal and the rations contained little or no animal protein, whereas 5 per cent of animal protein supplements was used in this experiment. It would thus appear that, apart from the improvement brought about by the action of water during the soaking period, the temperature of drying is a factor which affects the degree of improvement. Within limits, a higher drying temperature may be expected to give a better product.

TABLE 2.—EFFECT OF DRYING TEMPERATURE ON THE FEEDING VALUE OF WATER TREATED LINSEED OIL MEAL

Lot	Description of linseed oil meal	Initial body weight, gm.	Final body weight, gm.	Mortality per cent	Significance levels* Lots:		
					1	2	3
1	Untreated	60.5	132.6	33.3	—	—	—
2	Incubated with water, dried at room temperature	60.6	160.6	20.0	0.07	—	—
3	Incubated with water, dried at 60-70 degrees C.	60.5	163.3	33.3	0.06	—	—
4	Incubated with water, dried at 90-100 degrees C.	60.0	194.1	6.7	0.01	0.02	0.05

* The significance level of differences between final weights in any two lots is obtained by cross reference. The value for lots 2 and 4 is thus 0.02.

EXPERIMENT III

Methods and Materials

An aqueous solution of flaxseed mucilage was prepared as in Experiment I and divided into four parts. One portion was kept at room temperature for 24 hours, a second portion was autoclaved for 15 minutes at 250 degrees F., cooled and brought back to original weight with water, a third portion was dried in the oven at 80 degrees C., water added to redissolve the mucilage and brought back to original weight with water. The fourth portion was used immediately as control. The viscosity of these liquids was compared by noting the time of flow of a definite volume of the liquid under similar conditions through a vertically fixed tube of narrow and uniform bore. Results are given in Table 3.

Results and Discussion

It is seen from Table 3 that the time of flow and hence the viscosity of the mucilage is lowered by all the treatments, particularly by autoclaving and by drying. This effect may arise through changes in the colloidal nature of the solution. Water treatment of linseed oil meal with subsequent drying would therefore be expected to cause similar changes in the mucilage of linseed oil meal. In a similar way this may account for the varying degrees of improvement observed in the feeding trial in Experiment II.

TABLE 3.—VISCOSITY CHANGES IN AN AQUEOUS SOLUTION OF FLAXSEED MUCILAGE

No.	Sample	Time of flow in seconds
1	Untreated	915
2	Kept at room temperature for 24 hours	485
3	Autoclaved	122
4	Dried at 80° C. and redissolved	179

SUMMARY AND CONCLUSIONS

1. Flaxseed mucilage when incorporated into a starter ration containing 15 per cent soybean meal has a significant growth depressing effect on chicks and causes the development of beak necrosis.

2. In the improvement of linseed oil meal by water treatment, higher drying temperature has a greater beneficial effect.

3. The viscosity of aqueous solutions of flaxseed mucilage is appreciably reduced by autoclaving and by drying at 80 degrees C., and to a lesser extent by holding at room temperature for 24 hours.

4. It is suggested that the presence of the mucilage in linseed oil meal is one of the factors involved in its low feeding value for the chick and that the improvement in the meal as a result of higher drying temperatures in the water treatment process is partly due to alteration in physical properties, notably viscosity, of the mucilage.

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CYANOGENETIC GLUCOSIDES AND TRYPSIN INHIBITORS IN LINSEED OIL MEAL[1]

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Many workers have reported that linseed oil meal gives unsatisfactory results when used at levels over 5 per cent in chick starter rations (1), (5), (11), (12). Even after correcting amino acid deficiencies in the meal by adequate supplementation it caused significant growth depression in chicks (9). When it was used at 30 per cent levels in the ration high mortality and intestinal disorder were observed (3). These results have been taken as indicative of the presence of certain toxic factors in the meal. There is some evidence that linseed oil meal in the ration depresses the availability of some of the B-complex vitamins (6). It is believed also that other factors might be involved, namely, cyanogenetic glucosides and trypsin inhibitors. The presence of these factors in some vegetable feedstuffs is known to cause unsatisfactory results under certain conditions of feeding practice.

Flaxseed contains a glucoside which under favourable conditions of warmth and moisture liberates prussic acid by the action of an enzyme present in the seed (10). However, no specific instance of prussic acid poisoning has been reported in poultry. Ordinarily, the heat to which the ground seed is subjected during the oil expressing process inactivates or destroys the enzyme. Also, the addition to chick rations of potassium cyanide in amounts equivalent to the prussic acid content in some linseed oil meal samples did not lead to any poisoning effect.* It is possible, however, that different samples of the meal differ in the extent to which they liberate prussic acid.

The presence and properties of trypsin inhibiting factors have been extensively studied in the case of soybean (7), (8) (13), (14). These factors interfere with the normal action of tryptic enzymes in the digestive system and in this way depress the utilisation of the protein in the food. It would appear to be fairly well established that their presence partly accounts for the unsatisfactory feeding value of raw soybean for chicks. In view of the above reports it was felt that the possible implication of these two toxic factors should be more fully investigated in linseed oil meal.

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EXPERIMENT I

Methods and Materials

Three samples of linseed oil meal were used in this experiment, one being an expeller sample† designated (*c*) and the other two being hydraulic samples* designated (*f*) and (*h*). The concentration of hydrocyanic acid (free and combined) in these samples was determined according to the A.O.A.C. method of analysis for content of cyanogenetic glucosides in feedstuffs (2). Since in two of the samples studied the maximum liberation of hydrocyanic acid was obtained after four hours of maceration in water prior to steam distillation, this period was used instead of the recommended two-hour period. A feeding trial was also conducted on these samples of linseed oil meal. Week-old Barred Plymouth Rock chicks, 15 per lot, were placed on three starter rations containing the three samples of the meal at about 10 per cent level in the ration. The basal mixture consisted of the following ingredients per 100 lb.: ground yellow corn 20 lb.; ground wheat 20 lb.; ground barley 20 lb.; ground oats 13 lb.; buttermilk powder 2 lb.; fish meal (65 per cent protein) 2 lb.; meat meal (50 per cent protein) 3 lb.; soybean meal 1 lb.; alfalfa meal 5 lb.; dried brewer's yeast 1 lb.; ground limestone 2 lb.; iodized salt 1 lb.; fortified fish oil (1850 A-400D_3) 200 gm.; manganese sulphate 6 gm., and riboflavin 0.1 gm. Results of the experiment are given in Table I.

TABLE 1.—CYANOGENETIC GLUCOSIDES IN LINSEED OIL MEAL SAMPLES AND GROWTH RESPONSE OF CHICKS ON RATIONS CONTAINING THESE SAMPLES AT 10 PER CENT LEVEL

No.	Sample	Hydrocyanic acid per cent (free and combined)	Mean chick weight at 6 weeks, in gm.
1	Expeller (*c*)	0.004	199.2
2	Hydraulic (*f*)	0.038	250.0
3	Hydraulic (*h*)	0.050	291.4

Results and Discussion

It is seen from Table I that as the content of hydrocyanic acid (free and combined) in the samples increases their feeding value does not decrease. The expeller sample which gave the poorest results in the feeding trial yielded only traces of hydrocyanic acid. It is possible that the enzyme responsible for the liberation of hydrocyanic acid in this case had been inactivated by the relatively higher temperatures involved in the expeller process. Though the feeding quality of the meals would be determined by other factors as well—and hence they are not strictly comparable on the basis of the yield of hydrocyanic acid—this experiment would indicate that the importance of the cyanide content in the toxic effect of the meal is relatively small if existent at all.

† Kindly supplied by Victory Mills Ltd., Toronto.
* Kindly supplied by Canada Linseed Oil Mills Ltd., Montreal.

TABLE 2.—ENZYME HYDROLYSIS OF CASEIN IN PRESENCE OF RAW AND AUTOCLAVED AQUEOUS EXTRACTS OF LINSEED OIL MEAL AND OF FLAXSEED (EXPRESSED AS ML. OF 0.2 N ALKALI FOR FORMOL TITRATION)

Sample	Time of hydrolysis		
	3 hr.	7 hr.	17 hr.
(*a*) Casein plus enzyme	10.40 (10.65)*	11.70 (12.10)	13.45 (13.90)
(*b*) Enzyme alone	3.55 (3.70)	3.80 (3.85)	3.85 (4.05)
(*c*) Casein plus raw extract plus enzyme	10.50 (11.20)	11.90 (12.75)	13.65 (15.20)
(*d*) Raw extract plus enzyme	4.25 (4.20)	4.50 (4.35)	4.90 (4.65)
(*e*) Casein plus autoclaved extract plus enzyme	10 60 (10.90)	12.00 (12.45)	14.05 (14.40)
(*f*) Autoclaved extract plus enzyme	4.40 (4.15)	4.60 (4.10)	5.10 (4.30)
Casein alone (*a-b*)	6.85 (6 95)	7.90 (8.25)	9.60 (9.85)
Casein in presence of raw extract (*c-d*)	6.25 (7 00)	7.40 (8.40)	8.75 (10.55)
Casein in presence of autoclaved extract (*e-f*)	6.20 (6.75)	7.40 (8.35)	8.95 (10.10)

* The figures within brackets are values for flaxseed extracts. The other figures are those for linseed oil meal extracts.

EXPERIMENT II

Methods and Materials

A sample of linseed oil meal was prepared by extracting powdered flaxseed with petroleum ether in order to avoid the use of high temperatures. The extracted meal was mixed with ten times the amount of water, the pH adjusted at 4.0, the mixture kept overnight at 5 degrees C. and then centrifuged to obtain the clear aqueous extract. A portion of this extract was autoclaved for 15 minutes at 250 degrees F., cooled and made up to the original weight with water. The other portion was used in the raw state. Two mixtures were prepared, each containing 50 ml. of a 6 per cent casein solution, 10 ml. of 15 per cent di-sodium phosphate solution, 0.2 gm. of a dried pancreas preparation* of reported activity of 3 U.S.P. Units (1 : 75), and 1 ml. of toluene. To one mixture was added 20 ml. of the raw aqueous extract of linseed oil meal and to the other was added 20 ml. of the autoclaved extract. These mixtures were then incubated at 37 degrees C. and the pH maintained at 8.5 during the hydrolysis. Three blanks were run simultaneously under the same conditions, one containing the enzyme alone, another containing the enzyme with the raw extract and the third containing the enzyme with the autoclaved extract. The progress of the

*Kindly supplied by the Viobin Corporation, Monticello, Ill.

hydrolysis was measured by formol titration of 20 ml. aliquots at definite intervals. In a second experiment an aqueous extract of flaxseed was prepared in a manner similar to the preparation of the linseed oil meal extract, but the weight of water used was four times that of the flaxseed. A portion of the extract was autoclaved and the hydrolysis of casein in presence of the raw and autoclaved extracts was conducted in the same way as before. Results of both experiments are given in Table 2.

Results and Discussion

In Table 2 the extent of hydrolysis in casein alone and in casein in presence of the raw and autoclaved extracts, respectively has been calculated by subtracting the corresponding blanks. It is seen that the addition of the raw extracts (of flaxseed and linseed oil meal) had no appreciable effect on the hydrolysis of casein. Autoclaving the extracts likewise had little effect. The aqueous extract from uncooked soybean meal in a similar experiment was found to depress the trypsin hydrolysis of casein to a value as low as about one-third the original and this inhibition was destroyed on autoclaving the extract (13). The presence in linseed oil meal and in flaxseed of trypsin inhibiting factors similar to those present in soybean meal has therefore not been shown under these experimental conditions. "In vitro" trials of this type, however, may not identify all the enzyme inhibiting factors which in the digestive system of the chick would interfere with normal digestion.

The content of trypsin inhibitors in various feedstuffs has been reported since this work was undertaken (4). According to the data submitted, flaxseed does not contain these factors.

SUMMARY AND CONCLUSION

1. Data obtained on three samples of linseed oil meal indicate that increases in the yield of hydrocyanic acid liberated under incubation are not associated with corresponding decreases in the feeding value of the meals in chick rations.

2. The presence of raw aqueous extracts from linseed oil meal, and from flaxseed which should have contained the trypsin inhibiting factors, has little influence on the tryptic hydrolysis of casein. Autoclaved extracts likewise are without noticeable effect. These findings suggest that trypsin inhibitors are not present in these extracts to any appreciable extent.

3. It is concluded that the observed toxic effect of linseed oil meal in chick rations is due primarily to factors other than cyanogenetic glucosides and trypsin inhibitors.

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BOOK REVIEWS

JESSEN'S BOTANIK DER GEGENWART UND VORZEIT. Offset reprint edition. 495 pp. Chronica Botanica Co., Waltham, Mass.; Thorburn and Abbott, Ltd., Ottawa, Canada. Price $6.00.

This is a reprint of a history of botany originally published in 1864, and forms Volume 1 of a new series, entitled "Pallas," to be published by the Chronica Botanica Co., consisting of reprint editions of out-of-print and classic scientific works.

PRÉCIS DES DÉCOUVERTES SOMIOLOGIQUES, by C. S. Rafinesque. Reprinted from the original (1814) edition by Peter Smith, 321 Fifth Avenue, New York 16, N.Y. Introduction by E. D. Merrill, Arnold Professor of Botany and Director of the Arnold Arboretum of Harvard University. 1948. $4.00.

A reprint edition of 350 copies is available of this work, which, Dr. Merrill states, "is and always will be basic in reference to taxonomic studies of both plants and animals."

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THE VARIETAL COMPOSITION OF CANADIAN EXPORT WHEAT, 1926-1946[1]

A STUDY BASED ON TWENTY ANNUAL ANALYSES OF EXPORT CARGOES

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Canada's enviable reputation as a wheat producing country is built on the high quality of the wheat which she exports to other countries. Constant vigilance, however, has been necessary in order to maintain this high standard of excellence. In this, various agencies contribute, among which may be mentioned, first of all, the plant breeder who has given us good varieties. Next in importance, perhaps, is the Canadian Seed Growers' Association whose members multiply these approved varieties in a pure state and whose function is greatly aided and encouraged by the far-flung influence of the various Departments of Agriculture and Universities, and by such crop improvement agencies as those promoted by "The Crop Testing Plan", "The Line Elevators" and "The Wheat Pools". Then the general wheat producer applies his skill in producing and handling the commercial grain, and, finally, The Board of Grain Commissioners see to it that all wheat merchanised for domestic use or for export is given its proper grade.

About 1925, the wheat which Canada was producing was being criticized .in certain quarters because of the "undesirable mixture of varieties" of which it was believed to be composed. The Department of Agriculture, through the Cereal Division, Experimental Farm Service, initiated an annual survey of the varietal composition of the wheat composing a large number of cargoes, in order to obtain factual information on this point and, incidentally, to follow the expansion of the areas devoted to recently introduced varieties. At the beginning, these samples were drawn from cargoes of Canadian wheat as they arrived in Great Britain; but it was soon considered more desirable to have samples taken by officials of the Department of Trade and Commerce in Canada prior to shipping. Accordingly, arrangements were made whereby this material was collected by the staff of the Chief Grain Inspector, Board of Grain Commissioners, Winnipeg. The samples were taken while the ships were being loaded, which meant that the collecting period extended over a considerable length of time. Actually, in the case of boats loaded at Eastern ports, the collections are made from early September until the close of navigation in December. Boats loaded at Vancouver, on the other hand, are sampled from October until February.

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The data from the 1931 crop onward, therefore, are based chiefly on samples drawn in Canada by the Chief Grain Inspector's office. Data for the years 1926-1931 are also submitted, but these were obtained from "The Export Standards Grade" samples put up each season by the Grain Standards Committee to indicate the grading of the current year's crop. The latter samples, however, are of necessity put up from material gathered early in the season and are not thought to be truly as representative as the material on which the main part of this report is based.

The number of samples handled over the period 1931-1946, is indicated in Table 1.

TABLE 1.—PORTS FROM WHICH SAMPLES WERE OBTAINED

Grade	Vancouver	Fort William	Churchill	Montreal	Total
1 Northern	404	455	26	25	910
2 Northern	383	456	34	4	877
3 Northern	367	454	19	25	865
4 Northern	46	177	—	—	223
Total	1200	1542	79	54	2875

CANADIAN WHEAT VARIETIES

In order to obtain some idea of the scope of what is involved in this study, a reference to the history of wheat-growing in Canada and the expansion of the Canadian northwest is necessary. (The author has drawn extensively on "Essays on Wheat", by H. H. Buller for much of the following information.)

The first recorded attempts at the growing of wheat in Canada's Northwest were made by the Selkirk Settlers. This little band of pioneers was brought out from Scotland by Lord Selkirk to colonize 100,000 square miles of territory granted to him by the Hudson's Bay Company. The advance party arrived in August, 1812, and immediately commenced breaking sod in preparation for the next year's crop. Part of this was sown to winter wheat which they had brought with them. No crops were harvested, however, until 1815, as many tribulations dogged the efforts of the settlers. Early frosts, grasshoppers, plagues, ravages by birds and rival fur-traders all contributed to making wheat-growing extremely hazardous. Of the varieties in use at that time, nothing very definite is known, but, from the records, we are able to gather certain information. In 1868, the crop was almost entirely destroyed by grasshoppers and new seed was brought in from the United States. This wheat came chiefly from Minnesota, and probably was composed largely of Red Fife which had come into that State from Ontario. At any rate, further records show that small amounts of this variety were grown in Manitoba in 1870. In 1876, nearly 1,000 bushels of Red Fife seed were sent to Ontario for sowing in that province. This was the first wheat exported from Western Canada.

With the opening up of the country by the Canadian Pacific Railway, Red Fife seed was brought in from Minnesota and this was the variety sown by the company on all farms which it broke out of virgin sod as the

railway advanced across the prairies. The inducements extended by the Government in dropping the duty on imported seed wheat, and the offer of free transportation by the railway, gave the importation of this seed an added impetus. Thus Red Fife became the foundation on which Canada's reputation as a wheat-growing and exporting country was founded. Incidentally, Red Fife is found in the pedigree of the large majority of the good hard red spring wheats grown in Canada to-day.

While Red Fife was a good wheat from a quality standpoint, it was found to be too late in maturity for many parts of the Prairie Provinces. One of the first steps taken by the Dominion Experimental Farm System on its inauguration in 1886 was the extensive search for earlier maturing wheats (3). The story of this quest is a most compelling one, extending as it does over a long period of years. While several early wheats of good quality were produced, Marquis, introduced in 1909, was definitely the most outstanding. This variety, resulting from a cross made in 1892 between Red Fife and Hard Red Calcutta, swept the country as no other wheat has ever done. It has been estimated that by 1910 this variety composed 90 per cent of the hard red spring wheat grown in Canada and the United States. Marquis assumed such a prominent place in Canadian agriculture that it was adopted as the "yard stick" by which other varieties must be measured in so far as quality is concerned.

Many other varieties have been tried and discarded or released, but only those found in our export wheat at the start of this study are herewith listed. The others are rarely, if ever, found and are, therefore, of no interest as far as this study is concerned. The varieties are listed in the order in which they were grouped when this investigation was first initiated. (For further description of these varieties, see Handbook of Canadian Spring Wheat Varieties (4).)

Variety	Parentage
Marquis	Red Fife × Hard Red Calcutta
Garnet	Preston A × Riga M
Reward	Marquis × Prelude
Thatcher	(Marquis × Iumillo) × (Marquis × Kanred)
Apex	(H-44-24 × Double Cross) × Marquis
Renown	H-44-24 × Reward
Regent	H-44-T × Reward
Red Fife	Selection from Russian sources
Renfrew	Selection from Marquis
Ruby	Down Riga × Red Fife D
Red Bobs	Selection from Bobs
Ceres	Kota × Marquis
Early Red Fife	Selection from Red Fife
Type IC	Selection from Red Fife
Percy	Ladoga × White Fife
Reliance	Kanred × Marquis
Canus	Marquis × Kanred
Kota	Selection found in Durum
Coronation	Pentad × Marquis
Quality A	Burbank's Selection from Florence
Federation	Yandilla King × Purple Straw
Huron	Ladoga × White Fife
Pioneer	Riga × Preston
Preston	Ladoga × Red Fife
Stanley	Ladoga × Red Fife
Fisher's Selection	Selection from Marquis

Continued on page 100

Variety	Parentage
Parker's Selection	Selection from Marquis
Prelude	Downy Gehun × Fraser
Miscellaneous	Varieties resulting from natural crosses and otherwise
Ladoga	A variety of Russian orign
White Russian	A variety of Russian origin
Broatch's Selection	Selection made by J. W. Broatch
Club	A compactum type of wheat
Speltoid	A Spelt-like wheat type arising in common wheat varieties
Durum	Durum type wheats

OTHER CROPS SOMETIMES FOUND IN EXPORT WHEAT

Rye	Tame Oats
6 Row Barley	Wild Oats
2 Row Barley	

In making the analysis on these samples representing the individual grades everything found in the sample, including rye, barley and oats, was analysed and recorded, although they add little to the data and are generally within the limits for "foreign material other than wheat" allowed in the grade definitions.

ANALYSES OF EXPORT STANDARD GRADES—1926-1930

The data from the three Export Standard Grades 1, 2 and 3 Manitoba Northern are presented at this time primarily to give the reader an indication of the number of varieties and the percentages of each found in the Standards, at the time when criticism first arose. In this way it will be possible to follow the trend in both the number and the percentage of these varieties from 1926 to 1930 before the cargo samples were secured from the Chief Grain Inspector and made available for further study.

It will be noted in Table 2 that in 1926 over two-thirds of the wheat in the three Manitoba Northern Grades was composed of the Marquis variety, with the next largest percentages made up of Type IC, Renfrew, Kitchener and "Miscellaneous" types. In the succeeding four years, Red Fife increased and declined again, no doubt lagging behind the cycle of rust years when damage by rust or early frost would place this variety in the "Feed" grades. It was interesting to note that the Garnet and Reward varieties did not appear in the two top grades for two years after their introduction to the wheat-growing areas, but Garnet was found in the 3 Manitoba Northern Grade the first year after its introduction in 1926. Ceres appeared for the first time in 1928 and Reward in 1930. The Red Bobs Selections, made up of the Red Bobs, Early Triumph and Supreme varieties and grouped together throughout this varietal survey, are found in greater amounts in the 3 Manitoba Northern than in the higher grades. Ruby, first introduced as a war measure in 1916, had an up-surge in the top grade in 1928 when it reached an all-time high of 17.6 per cent, but it has been declining ever since. Early Red Fife reached its peak in the 1 and 2 Manitoba Northern in 1929. The other varieties, mostly of medium and poor milling and baking quality, were found in small or trace percentages, but have been recorded in order to provide as complete a picture as possible of what was actually found in Canadian Export Wheat during this period.

TABLE 2.—VARIETAL ANALYSIS OF EXPORT STANDARD GRADES FOR YEARS 1926-27-28-29-30. (PERCENTAGE)

	Grade 1 Manitoba Northern						Grade 2 Manitoba Northern						Grade 3 Manitoba Northern					
	1926	1927	1928	1929	1930	Average	1926	1927	1928	1929	1930	Average	1926	1927	1928	1929	1930	Average
Marquis	66.01	77.05	53.61	61.39	76.80	66.97	72.02	68.72	59.69	44.39	66.97	62.36	62.75	53.65	52.70	43.47	52.47	53.01
Garnet	—	—	0.27	0.36	3.31	0.79	—	—	3.78	14.24	15.01	6.61	—	1.52	2.52	14.85	11.71	6.16
Reward	—	—	—	—	2.00	0.40	—	—	—	—	0.85	0.17	—	—	—	—	0.27	0.05
Red Fife	—	2.36	14.25	14.02	3.76	6.88	1.48	3.09	14.41	11.43	6.23	7.35	5.03	3.96	19.58	13.34	8.07	10.00
Ruby	1.96	—	17.69	0.48	2.58	4.54	—	1.40	2.68	1.68	1.31	1.41	—	12.50	2.70	4.49	0.40	4.02
Red Bobs Sel.	0.65	1.76	0.37	2.39	0.37	1.10	0.29	—	1 22	5.27	0.33	1.43	1.34	6.70	4.40	3.34	3.53	3.87
Ceres	—	—	0.08	0.60	1.47	0.43	—	—	—	0.56	0.72	0.26	—	—	0.06	0.69	0.20	0.19
Early Red Fife	1.96	0.88	1.52	3.59	0.15	1.62	0.89	—	1.25	3.03	—	1.03	2.34	5.79	1.25	1.84	0.33	2.31
Type IC	5.55	0.29	4.87	6.11	4.35	4.23	1.48	5.39	1.55	6.05	2.23	3.34	2.34	—	3.16	4.49	12.80	4.56
Kota	1.63	0.58	0.57	0.72	1.25	0.95	0.59	0.57	1.71	0.67	0.72	0.85	1.34	0.91	0.39	0.35	1.13	0.82
Pioneer	—	—	—	—	0.22	0.04	—	—	0.31	0.34	0.20	0.17	—	—	—	—	—	—
Renfrew	3.59	3.82	0.78	2.15	0.52	2.17	—	3.66	3.22	1.91	0.72	1.90	3.02	0.91	1.36	0.35	0.60	1.25
Kitchener	5.25	2.05	1.36	6.11	0.30	3.01	3.86	2.54	4.27	4.37	0.20	3.05	4.68	1.82	5.65	3.68	1.13	3.39
Huron	0.98	0.58	0.15	—	—	0.34	1.48	1.40	0.17	1.12	—	0.83	1.34	1.82	0.32	1.15	0.07	0.94
Preston	—	0.29	0.14	—	0.15	0.12	—	—	0.17	0.45	0.33	0.19	—	—	0.37	0.35	0.07	0.11
Stanley	—	—	—	0.48	—	0.10	0.59	0.28	0.35	1.12	0.46	0.56	—	0.30	0.53	1.38	0.47	0.54
Parkers Sel.	—	—	—	—	0.30	0.06	—	—	—	—	0.39	0.08	—	—	0.06	0.23	.20	0.09
Fishers Sel.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.07	0.01
Miscellaneous	12.41	10.29	2.67	0.96	1.40	5.55	16.96	12.95	3.47	1.79	2.88	7.61	15.76	9.44	2.93	2.77	4.00	6.98
Ladoga	—	—	1.60	0.36	0.66	0.24	—	—	1.51	1.35	0.26	0.62	—	—	1.87	3.11	1.07	1.21
Federation	—	—	—	—	0.22	0.04	—	—	—	—	—	—	—	—	—	—	—	—
Club	—	—	—	—	—	—	—	—	—	—	0.07	0.01	—	—	—	—	—	—
Vermilion	—	—	—	—	—	—	—	—	0.06	0.11	—	0.03	—	—	—	—	—	—
Speltoid	—	—	—	—	—	—	—	—	—	—	—	—	—	0.30	—	—	0.47	0.15
Durum	—	—	—	—	0.15	0.03	—	—	0.13	—	—	0.03	—	—	0.12	0.12	0.40	0.13
6 Row Barley	—	—	—	—	0.07	0.01	—	—	—	—	0.07	0.01	—	—	—	—	0.47	0.09
2 Row Barley	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.07	0.01
Tame Oats	—	—	—	—	—	—	0.29	—	—	—	0.07	0.07	—	0.30	—	—	—	0.06
Wild Oats	—	—	—	0.24	—	0.05	—	—	—	0.11	—	0.02	—	—	—	—	—	—

On examination of the five-year averages, it will be noted that the varieties which are now eligible to go into the 1 and 2 Manitoba Northern Grades (4), make up the following percentages of these grades.

	1 M.N. per cent	2 M.N. per cent	3 M.N. per cent
Marquis	67.97	62.36	53.01
Reward	0.40	0.17	0.05
Red Fife	6.88	7.35	10.00
Ruby	4.54	1.41	4.02
Red Bobs Selection	1.10	1.43	3.87
Ceres	0.43	0.26	0.19
Early Red Fife	1.62	1.03	2.31
Type IC	4.23	3.34	4.56
Pioneer	0.04	0.17	—
Renfrew	2.17	1.90	1.25
	89.38	79.42	79.26

The following varieties were not grown in this period:

Thatcher, Apex, Renown, Regent.

It is evident from these data that the introduction of the new varieties had the tendency to reduce the percentage of mediocre and poor quality wheat varieties rather than having the opposite effect as was claimed by some; nor has the trend in later years lent any support to this latter claim. This will be brought out in the discussion in the text based on the tables to be found in the Appendix of this report.

Trends in Overseas Cargoes

ATLANTIC CARGOES

With the trends indicated in the Export Standard Grades as a background, let us now examine the "Official Samples" supplied by the Chief Grain Inspector for the crop years 1931-1946, inclusive, except for those belonging to the 1942 crop year. The samples from the 1942 crop, when grown at Ottawa, suffered so badly from adverse weather that the varietal data were not considered sufficiently reliable and have therefore, not been included in Tables A1 to A12 which are to be found in the Appendix.

1 Manitoba Northern Grade Samples
Ex Fort William, Ontario

A close study of Table A1 which deals with the 1 Manitoba Northern Grade shipped from Fort William, Ont., reveals extremely interesting trends in the varietal make-up of this grade over the period studied. It will be noted that Marquis held a premier position until 1937 when a series of events took place which have had a marked effect on the varietal composition of our wheats. That year, stem rust and drought were both serious, and seed was brought in from Alberta to relieve the shortage in supply caused by a succession of poor crops in Saskatchewan. One of the varieties grown to a considerable extent in Alberta was Red Bobs; this accounts for the sudden increase noted in the percentage of this variety in

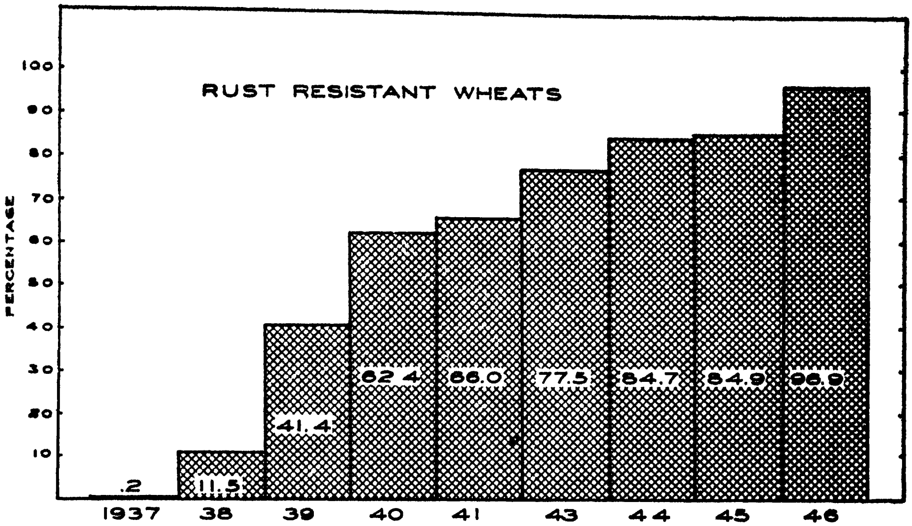

FIGURE 1. Increase in percentage of rust-resistant wheats in 1 Manitoba Northern cargoes. Ex Fort William, 1937-1946, inclusive.

this 1 Manitoba Northern Grade in 1937. It has declined steadily from that time to date. Thatcher wheat, a stem rust-resistant variety developed at the University Farm, St. Paul, Minnesota, was just making its appearance at this period, having been introduced into Canada in 1935. This new wheat survived the stem rust and drought better than "the relief seed", and from then on Thatcher has increased very rapidly. By 1945, 80 per cent of this grade was made up of this one variety. In 1939, two new rust-resistant wheats, Apex and Renown, were just appearing in the cargoes and Regent followed a year later. With the introduction of these four new rust-resistant wheats there followed a rapid and almost complete decline in the percentages of the rust-susceptible varieties grown. This condition has been quite marked in the last six years when the average percentage of rust-resistant varieties has increased from 2.2 per cent in 1937 to 96.9 per cent in the samples analysed for 1946. This is graphically represented in Figure 1.

A glance at Table A1 further shows that the various other varieties in this grade have also been declining rapidly and by 1946 had either disappeared or were only found in minute quantities.

It should be borne in mind when examining these data that Table A1 in the Appendix represents anywhere from twenty-five to fifty cargoes for any one year and that, in the average itself, the percentage of any one variety indicated may be made up from only a few cargoes. In other words some varieties may occur a relatively few times, while others will be found in every crop year. For instance, Marquis was found in every cargo of 1 Manitoba Northern in 1931, ranging from 51.7 per cent to 83.4 per cent in individual cargoes. Type IC on the contrary ranged from 0.4 to 20.1 per cent. In the 1946 cargo samples Marquis was found in only twenty of the twenty-five cargoes and ranged from zero to 5.0 per cent, while Thatcher and Regent were in every one of the twenty-five

cargoes. In the case of Thatcher, the range was from 32.4 to 94.4 per cent and Regent from 1.4 to 49.7 per cent. Other varieties ranged from zero upwards. Instances have been observed where a large cargo composed of 340,000 bushels was made up of not more than seven varieties and all of those eligible for the 1 Manitoba Northern Grade.

In 1931, when official samples were first supplied, Marquis, Reward and *Type IC were the leading varieties in the 1 Manitoba* Northern Grade. These three varieties made up a total of 84.5 per cent of the wheat verified.

2 Manitoba Northern Grade Samples
Ex Fort William, Ontario

The trend in the samples taken from the 2 Manitoba Northern Grade follows the same general course as in the preceding grade, but with this difference: The Marquis content in 1931 to 1934 remained at much the same level, with Garnet taking a close second place. When the policy of grading Garnet separately was adopted in 1935, the percentage of Marquis in this grade increased until the appearance of the new rust-resistant varieties began to manifest itself. Since then Marquis has decreased very rapidly until by 1944 it reached a negligible place.

The bad rust year, 1936, had the same effect on the 2 Manitoba Northern Grade as already noted in the higher grade, with a decrease in Marquis and an increase in Red Bobs Selection in 1937. From 1939 on, the rust-resistant varieties have taken up a large percentage of this grade. In that year, the four varieties, Thatcher, Apex, Renown and Regent made up 60.5 per cent of the grade and this percentage increased to 89 per cent in 1944, then dropped to 85 per cent in 1945 and in 1946 reached 96 5 per cent of the grade. There was a corresponding gradual tapering off in such varieties as Red Fife, Ruby, Pioneer, Kota, Coronation and Type IC in the same years. Actually, only Type IC of these six varieties appeared in the 1946 crop samples. While the actual number of varieties between 1931 and 1946 had changed only slightly, the percentage of many has noticeably lessened. Many mediocre and poor quality wheats have been replaced by good rust-resistant varieties.

In this grade the percentages of rust-resistant wheats have gradually increased over the last nine-year period, with the average just slightly lower than for the average of the next grade above. This is clearly to be seen in the Figure 3.

3 Manitoba Northern Grade Samples
Ex Fort William, Ontario

In the 3 Manitoba Northern Grade, much the same trends are noted as in the Grades 1 and 2. The percentage of Marquis reached its peak in 1935 and after 1938 declined rapidly, being replaced chiefly by the rust-resistant wheat variety Thatcher, which reached its highest percentage for the fifteen-year period in 1946. The other rust-resistant wheats, Apex and Renown, appeared in this grade in 1939 with Regent appearing a year later. By 1940, the percentage of these four resistant wheats comprised 68.4 per cent of the wheat in this grade and the peak for these varieties was reached in 1946 when the percentage hit 92.9 per cent. It declined in 1944 but rose again to 82.6 per cent in 1945, with an average for the fifteen-year period of 37.6 per cent.

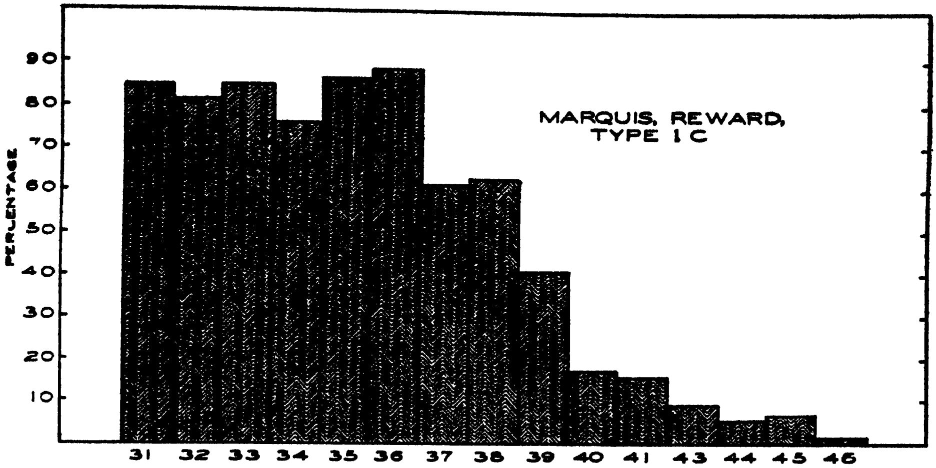

FIGURE 2. Combined percentages of Marquis, Reward and Type IC wheats found in 1 Manitoba Northern cargoes. Ex Fort William, 1931-1946, inclusive.

Red Bobs was relatively unimportant until 1938, when it increased to 21 per cent. It, however, decreased to a low of 1.1 per cent in 1946, and was largely replaced by Thatcher. For the fifteen-year period, Red Bobs ranked fourth in the average percentage of the varieties comprising this grade.

The twenty-five cargoes of the grade examined each year for the period 1941 to 1946 indicate that from 95.8 to 97 per cent of the grade was made up of the following six varieties: Marquis, Thatcher, Apex, Regent, Renown and Red Bobs; and in only one case did the percentage of any of these varieties fall below 1 per cent of the total (Marquis 0.27 per cent in 1944).

Garnet reached its maximum percentage in 1937, then decreased to obscurity as in the other Northern grades. Reward, which in 1934 made up 8.8 per cent, had steadily declined until by 1946 it reached trace proportions.

4 Manitoba Northern Grade Samples
Ex Fort William, Ontario

The data in Table A4 in the Appendix provide information on the 4 Manitoba Northern Grade for an eight-year period only. They indicate that the trend in the varieties of wheat found in these cargoes from Fort William remains much the same as in the other grades already discussed. The percentage of Marquis, starting at 55.2 per cent in 1938, declined rapidly after 1940, reaching a low point of less than ½ of one per cent in 1944, but rising slightly in 1945 to 11.0 per cent and again dropping to less than 5 per cent in 1946. Marquis was largely replaced by the Thatcher variety which, along with the other rust-resistant wheats, including Apex, Renown and Regent, has steadily assumed a greater share of the total. This is brought out in the accompanying histogram (Figure 4).

The combined percentages of the following seven wheats—Marquis, Reward, Thatcher, Apex, Renown, Regent and Red Bobs have been exceptionally high in relation to the other varieties found in this 4 Manitoba

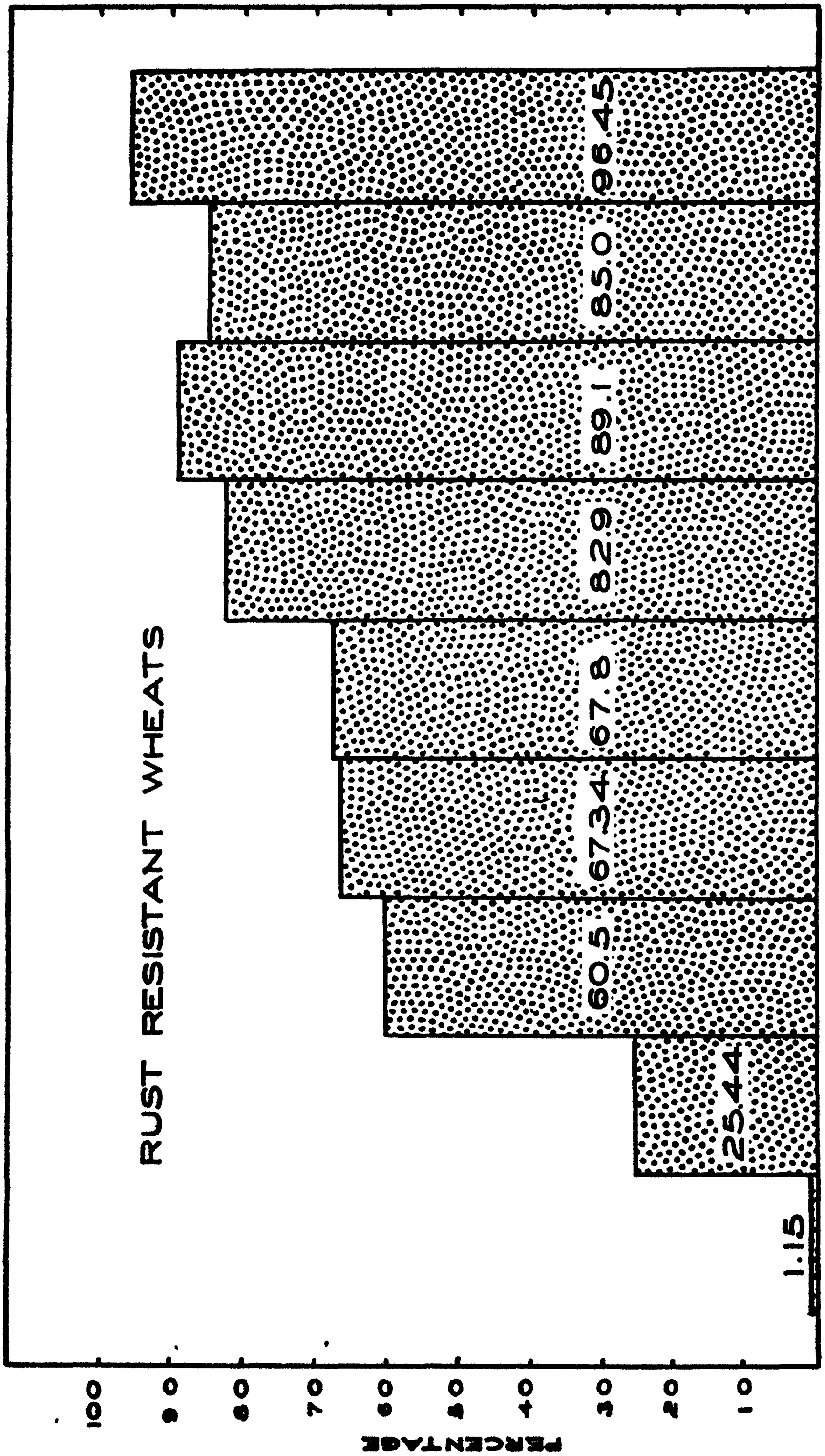

FIGURE 3. Combined percentages of Thatcher, Apex, Renown and Regent in 2 Manitoba Northern cargoes. Ex Fort William, 1937-1946, inclusive.

Northern Grade. There has never been a year in the period under consideration (1938-1946) when these seven varieties have not made up from 90 to 97.8 per cent of the total wheat in this grade, except in 1938 when this figure was only 81.6 per cent. During the above period, Reward has steadily declined from 8.2 per cent to zero in 1946. The interesting point in this Grade is the fact that the number of wheat varieties making up the Grade has never been as high as in the higher grades. The range covered from 25 varieties in 1943 to only 16 in 1946, when as already noted, 97.8 per cent of the grade was made up of less than seven varieties. Many of the varieties found in the earlier years were either only found in traces or were entirely absent from the 1946 crop samples.

PACIFIC CARGOES

The varietal composition of the wheat shipped from the Pacific Coast of Canada has not undergone the radical change which has characterized that produced in areas farther east during the period under investigation. This is due primarily to the fact that Alberta lies well to the west of the area where rust may be a serious factor. Farmers in this area, therefore, have not found it so necessary to change over to varieties capable of resisting this disease. Throughout the fifteen crop years studied, Marquis and Red Bobs have been consistently the two outstanding varieties in so far as the percentage grown is concerned. In more recent years, Thatcher and some of the other rust-resistant varieties have made appreciable gains due to their yielding ability rather than to their rust-resistance. The suitability of Red Bobs as a combine wheat, where this method of harvesting is practised in Alberta, has been an important factor in the continued popularity of this variety in this province. Being highly susceptible to wheat stem rust, however, Red Bobs has practically disappeared from the provinces farther east.

1 Manitoba Northern Grade Samples
Cargoes Leaving Vancouver, B.C.
(For Years 1931-1946, inclusive)

Again referring to the Appendix, it may be noted in Table A5 that there is the same general trend in the percentage of Marquis found in the Manitoba Northern cargoes from Vancouver as is indicated in Table A1 dealing with 1 Manitoba Northern shipments from Fort William. The percentage of Marquis in the Pacific cargoes, however, is always lower than that from Fort William, with the exception of four years—1940, 1941, 1945 and 1946. The average for the period is approximately 10 per cent lower. Until 1937, the average annual percentages of Marquis in the Pacific cargoes were practically the same, but gradually declined after this date to reach a low of 0.29 per cent in 1944; an upward swing again occurred in 1945. Garnet and Reward followed similar paths in this grade from both east and west ports but, as might be expected from the statement already made, the rust-resistant wheat varieties in the Vancouver cargoes have not increased as rapidly as in their eastern counterparts. The percentage of Thatcher in 1944 crop was the first big upward surge indicating the increasing popularity of this variety. The average content of the four rust-resistant varieties that year made up 44.8 per cent of the cargoes,

declining to 16.7 per cent in 1945. Where the Vancouver cargoes have varied most noticeably has been in the Red Bobs content. From 1934, the average content of the latter variety has increased rapidly, reaching a high of 71.5 per cent in 1941, but has since declined from this level.

The number of wheat varieties found in this grade have closely followed those of the corresponding grade in the Fort William shipments, the difference being in the percentage of each variety found.

In 1931, Marquis, Reward, Red Fife and Red Bobs and Type IC were the main varieties contributing to the 1 Manitoba Northern Grade shipped from Vancouver, making up 85.6 per cent of the wheat in those shipments. From 1937 on, the percentage of those varieties, plus the four rust-resistant wheats as they came into the grades, has only been below 94.5 per cent once and in 1941 the percentage reached 97.2. The number of wheat varieties found in this 1 Manitoba Northern Grade cargoes from Vancouver does not seem to follow any well defined trend. The greatest number of varieties found in any year was 28 in 1933 and 1934 when 50 cargoes were examined, and the lowest was 13 in 1939 when only 13 cargoes were examined. In 1943 with twenty-five cargoes verified, the number of varieties was again up to 24, the greater number of cargoes examined per year naturally providing greater opportunity for additional varieties.

2 Manitoba Northern Grade Samples
Ex Vancouver, B.C.

This group of three hundred and eighty-four wheats provides no parallel with any of the other grades yet examined. The trends, as noted in Table A6 in the Appendix, are erratic and several crests appear in the main varieties making up these grade cargoes from the Port of Vancouver for the years concerned.

The percentage of Marquis over the fifteen-year period varies greatly, running with fair uniformity from 1931 to 1935 when it hit the highest level in the full period being considered. It then declined until 1941 when this variety again ran up to 43.6 per cent and receded to 1.3 per cent in 1944. In 1945 and 1946 the average Marquis content was over 12 per cent. The Garnet content of this 2 Manitoba Northern Grade was the high ranking variety until 1935 when the special grades which were introduced for this variety caused it to fall away into the "Trace" category. Reward did not make much headway in this grade and never averaged over 7.8 per cent. Thatcher, starting to appear in 1937, made rather slow progress in the Pacific Cargoes until 1943 when it jumped to 10.7 per cent and has steadily risen since then, making up nearly one-third of the percentage of this grade in 1946. It is likely to become one of the leading varieties in future.

None of the other varieties has a high content in this grade except Red Bobs which replaced Garnet as the leading variety from 1936 on; and for the fifteen-year period comprised on the average over 46 per cent of the wheat of this grade examined and shipped from this Pacific Port.

The number of varieties making up this 2 Manitoba Northern Grade has been consistently higher than in the grade above it. In fact, this whole grade presents a specially interesting study in that it has been

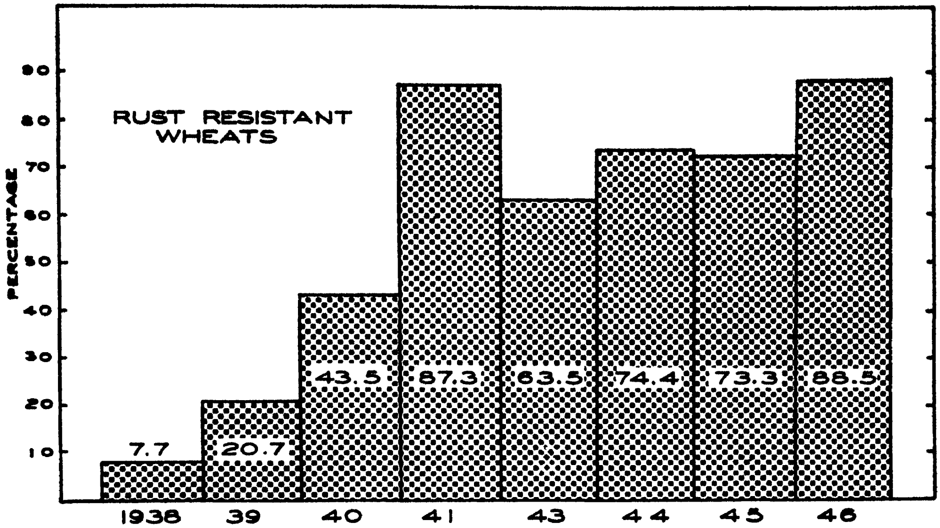

FIGURE 4. Combined percentages of rust-resistant wheat varieties in No. 4 Manitoba Northern cargoes. Ex Fort William, 1938-1946, inclusive.

practically carried on three varieties. At the start in 1931 with Marquis, Red Bobs and Garnet, making up 81 per cent of the total, and after 1935 when Garnet was placed in a special grade, Marquis, Red Bobs and Thatcher made up 76 to 93 per cent of this 2 Manitoba Northern Grade. In 1941, only two cargoes were sampled and the data for that year should be considered with caution in so far as the number of varieties comprising the grade for that year is concerned.

3 Manitoba Northern Grade Samples
Ex Vancouver, B.C.

The data found in Table A7 in the Appendix on these three hundred and sixty-seven 3 Manitoba Northern Grade samples provide interesting material for study. Into this grade has fallen material which has been disallowed in the higher grades, and yet it contains a high proportion of good milling and baking wheats over the fourteen-year period, 1942 and 1944 not being represented by samples from cargoes in these years.

The Marquis content of this grade fluctuated widely from 33.1 per cent in 1931 to 3.2 per cent in 1943, but has only followed this definitely downward trend since 1939, although three regressions have been noted in the fourteen-year period. The average for the period was approximately 12 per cent. Garnet, however, in the same period has roughly contributed 30 per cent of the wheat of this grade, although since 1937 it has dropped down to a low of 1.2 per cent in 1943. Thatcher was a year later in making its appearance in this grade than in 1 and 2 Manitoba Northern Grades but increased much more rapidly until by 1946 it comprised 40 per cent of the wheat in this grade. In fact, the percentage of Thatcher for that year in this grade is 10 per cent higher than in the two higher grades already examined and the data in Table 3 are given to bring this point out.

TABLE 3.—PERCENTAGE OF THATCHER WHEAT IN 1, 2 AND 3 MANITOBA NORTHERN GRADES

Per cent	1°	2°	3°
Thatcher	27.9	31 2	40 0

The other rust-resisting wheats were not only delayed in appearing in this Grade, but never contributed materially to the total.

The Red Bobs selections have always been large contributors to the 3 Manitoba Northern Grade, but since 1938 have the major position, with the average content over the period just slightly higher than that held by Garnet, and over twice that of Marquis. The high percentage of this variety in 1941 should be considered in the same light as the cargoes of the 2 Manitoba Northern Grade, in that only two cargoes were sampled to provide these data. The high content of the twenty-five cargoes in 1943 and 1946 and the twenty in 1945, however, demonstrates that Red Bobs has continued to be the big contributor to this Grade. There does seem to be a slight tendency to decline in the face of the increasing popularity of Thatcher, which, as has been noted above, increased materially in the 1946 cargoes.

TABLE 4.—COMPARISON OF THE NUMBER OF VARIETIES IN 3 MANITOBA NORTHERN WHEAT—EX. VANCOUVER, B.C. FOR PERIOD 1931 TO 1946

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1943	1945	1946	Aver.
Number of Varieties	23	25	24	30	21	19	20	22	15	18	12	21	23	21	21

The comparison of the number of varieties in 3 Manitoba Northern Wheat found in Table 4 indicates that apparently there has not been any marked reduction in the average number of varieties found in the cargoes over the fourteen-year period aside from 1939, 1940 and 1941 when only a few cargoes were verified. The average of 21 for the period, however, may be misleading for it will be noted that there were in all some 39 different varieties found in this grade over the next fourteen-year period, while in the higher grade only 34 varieties were identified and 38 in the top grade.

4 Manitoba Northern Grade Samples
Ex Vancouver, B.C.

Owing to the relatively small number of samples from cargoes of 4 Manitoba Northern wheat shipped from Vancouver which has been supplied for verification, it would be unfair to lay claim to any trends in the percentage of any variety of wheat found, or the number of varieties which make up those cargoes. Only three seasons, 1938, 1943 and 1946, are represented, with a total of only forty-six cargoes for those three seasons. The data in Table A8 in the Appendix, however, are recorded as a matter interest and comparison.

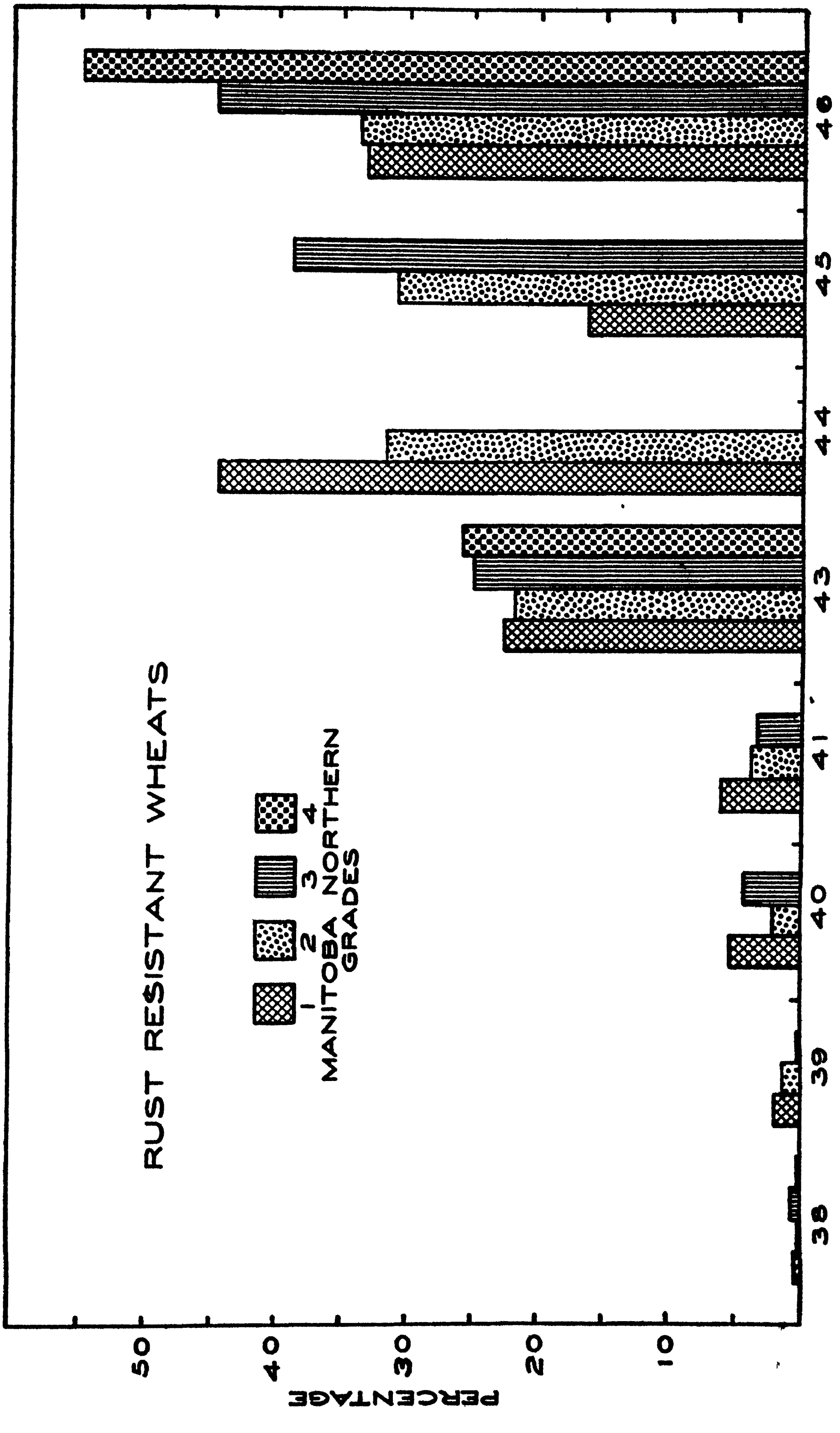

FIGURE 5. Comparison of the percentage of rust-resistant wheats in 1, 2, 3 and 4 Manitoba Northern cargoes. Ex Vancouver, 1938-1946.

Comparing this 4 Manitoba Northern grade with the 3 Manitoba Northern referred to above, it is found that Marquis in the 3 Manitoba Northern Grade was declining in 1938 and reached a low of 3.19 per cent in 1943. In the 4 Northern Grade, however, there was no Marquis found in the two of the 1943 cargoes examined, while Thatcher had increased to such an extent that it comprised over 46 per cent by 1946. The Red Bobs selections declined materially by 1946.

The interesting point to observe in this Grade was the complete elimination of many of the varieties found in the three higher grades. With data obtained from 19 cargoes in 1946 it will be noted that there are only sixteen varieties found compared to 24 in 1938. The 13 found in 1943 are hardly comparable inasmuch as these data were derived from only 2 cargoes in that year.

In 1938, Marquis, Thatcher and Red Bobs made up 73.6 per cent of this grade; in 1943, the average was 1 per cent higher without any Marquis, while in 1946 these same three varieties made up 86 per cent of the grade.

The rust-resistant wheats in the four Grades under consideration out of Vancouver present an interesting comparison and the data indicate that the combined percentages of the four rust-resistant varieties—Thatcher, Apex, Renown and Regent—increased gradually from 1 to 4 Manitoba Northern Grades.

This comparison (Figure 5) indicates the increase in percentage of the rust-resistant wheats in the 1, 2, 3 and 4 Manitoba Northern Grade Cargoes Ex Vancouver.

It should be noted that there were no cargoes in any of the four grades in 1942, and in 3 Manitoba Northern 1944 was missing; while in the 4 Manitoba Northern Grade only three years were represented.

FORT CHURCHILL, MANITOBA, SAMPLES

Samples from the Port of Fort Churchill were not always sent in for verification, largely because there were comparatively few cargoes moving out of that northern port.

However, between 1935 and 1946 samples from twenty-six cargoes were secured and the data obtained are recorded in the Appendix Table A9.

1 Manitoba Northern Grade Samples Ex Churchill, Manitoba, for Period 1935-1946

This grade of wheat leaving Canada's most northerly port carries a higher Marquis content by a wider margin than either the Fort William or the Vancouver shipments for either comparable years or over the longer period for these other ports.

TABLE 5.—COMPARISON OF MARQUIS CONTENT IN PER CENT IN 1 MANITOBA NORTHERN GRADE FROM THE PORTS OF CHURCHILL, FORT WILLIAM AND VANCOUVER

Period	Churchill	Fort William	Vancouver
1935-1946	56.6	47.2	37.2
1931-1946	—	37.2	32.3

The Garnet content on the average is very similar to that of the Fort William and Vancouver shipments for the same years. The Thatcher content is much higher in the 1938 cargoes than the Fort William, but less than the Fort William cargoes in 1939 and 1946.

In 1937, 1938 and 1939, the Red Bobs content did not conform to the content of this grade from either of the other ports. This can be explained by the fact that cars of wheat drawn for inspection, passing through the Port of Churchill, come from the northern part of Saskatchewan where Red Bobs is not grown to any extent.

The 11 to 15 per cent made up of Early Red Fife and Type IC in 1935, 1936 and 1937 has been replaced by Thatcher in 1938 and 1939 when the interest in the importance of Thatcher became established. A comparison of the percentage of Marquis, Reward, Red Bobs, Early Red Fife and Type IC wheat varieties will be dealt with after discussing the 2 and 3 Manitoba Northern Grades from this port.

These Churchill shipments present an entirely different aspect to the varietal picture than can be found in those from Fort William and Vancouver. While the number of cargoes examined from Churchill in any one year is relatively small compared to the two latter ports, nevertheless it is interesting to note the trend in varieties based on those data. In 1935, at least traces of nearly every variety listed were found, while by 1946 only those in the upper two-thirds of the list were found, many of these in Trace proportions, with 71 per cent made up entirely of rust-resistant varieties.

2 Manitoba Northern Grade Samples
Ex Churchill, Manitoba

The Table No. A10 in the Appendix provides data for this group of samples and it will be noted that the 2 Manitoba Northern Grade cargoes shipped out of the Port of Churchill, represented by only thirty-four samples, vary quite widely in the percentage of Marquis found from year to year, which, for the years 1935 to 1939 ranged from 35.7 to 66.0 per cent. This range was relatively narrower than was the case in the Fort William cargoes, .but wider than the Vancouver cargoes for the same years. The percentage of Marquis found in 1943, however, was lower than either of the other ports of shipments. The Thatcher content in this grade increased more rapidly than in either the 1 or 3 Manitoba Northern grades, and by 1943, became the dominating variety in this Grade. The other varieties made much the same contribution to the cargoes as in similar grades from the other ports, Red Bobs making a sudden upward swing in 1938, but dropping off by 2 per cent in each of the years 1939, 1943 and 1946. The rust-resistant varieties, aside from Thatcher, were not heavy contributors to this grade.

The 3 Manitoba Northern Grade, data on which will be found in Table A-1, represented by nineteen cargoes, contained a higher and more uniform Marquis content for the 1935 and 1939 period than was found in similar grades from the other ports. In the years 1940, 1941, when no samples were supplied, the rust-resistant varieties—Thatcher, .Apex, Renown and Regent—made great headway so that, from 1943 to 1946, these four rust-resistant varieties increased from 62.3 per cent to 93.6 per

cent in the cargoes. The Red Bobs selections, along with Early Red Fife and Type IC, have never been heavy contributors to this grade and reached a new low in 1946.

The number of varieties making up this grade never was high but in 1946, on the data derived from 2 cargoes, an all-time low of eight varieties was reached. The varieties making up these 1946 shipments are those mainly responsible for the bulk of this grade in previous years and Table 6 is made up principally from these same varieties.

TABLE 6.—COMPARISON OF COMBINED PERCENTAGES OF MARQUIS, REWARD, RED BOBS, EARLY RED FIFE, TYPE IC AND THE FOUR RUST-RESISTANT WHEATS, THATCHER, APEX, REGENT AND RENOWN, SHIPPED FROM CHURCHILL, MANITOBA, 1935*-1946

Grade	1935	1936	1937	1938	1939	1943	1946	Average 1935-1939	Average 1935-1946
1 Man. Nor.	88.1	94.6	84.6	97.4	94.3	—	98.3	91.8	92.9
2 Man. Nor.	80 5	89.3	70.0	93.0	92.5	94.4	98.0	85.1	88.2
3 Man. Nor.	63.7	59.6	45.0	78.2	87.6	88.4	98.3	66.8	74.4

* 1940, 1941, 1942, 1944, 1945 not represented.

The data in Table 6 indicate that for the years under consideration, 1935-1946, the combined percentages of certain wheats varied with the grade from year to year but that the percentages in the lower grades rose steadily so that by 1946 all these grades had practically reached the same high level of 98 per cent.

CARGOES LEAVING PORT OF MONTREAL

The one year in which cargo samples were obtained from this port covered the 1935 crop season and, as the number of samples was representative, the data for that year can be compared without any reservations. In Table A12 in the Appendix, it will be noted that the percentage of Marquis was well maintained in all grades, although lower than those from the Port of Fort William for the same grades and year. The Garnet

TABLE 7.—COMPARISON OF THE NUMBER OF WHEAT VARIETIES ENTERING 1, 2 AND 3 MANITOBA NORTHERN GRADES FROM THE PORTS OF FORT WILLIAM, VANCOUVER AND MONTREAL FOR YEARS 1931-1946

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1943	1944	1945	1946
1°															
Fort William	20	26	26	28	22	22	24	24	16	22	21	20	20	17	15
Vancouver	24	23	27	28	22	21	22	24	13	16	17	24	18	19	21
Churchill	—	—	—	—	20	18	12	14	11	—	—	—	—	—	16
Montreal	—	—	—	—	23	—	—	—	—	—	—	—	—	—	—
2°															
Fort William	23	26	25	25	23	23	24	23	21	24	21	21	21	17	17
Vancouver	21	25	25	27	21	21	25	23	18	16	11	23	17	22	25
Churchill	—	—	—	—	18	18	16	14	17	—	—	20	—	—	17
Montreal	—	—	—	—	20	—	—	—	—	—	—	—	—	—	—
3°															
Fort William	27	26	25	25	25	18	23	25	19	23	19	19	19	21	16
Vancouver	23	25	24	30	21	19	20	22	15	18	12	21	—	21	21
Churchill	—	—	—	—	13	15	14	13	13	—	—	18	—	—	8
Montreal	—	—	—	—	24	—	—	—	—	—	—	—	—	—	—

content was relatively high in the 3 Manitoba Northern Grade but it must be remembered that Garnet was not graded separately till the year 1937. Reward content remained high for this variety and Type IC was uniform across the three grades. The number of varieties making up each grade was fairly uniform, considering that the 2 Manitoba Northern Grade was composed of only four varieties.

The data in Table 7 clearly indicate that the introduction of new varieties in recent years has tended to gradually reduce the number of varieties found in the Overseas Cargoes; whereas the 20-27 varieties found in the 1931 cargoes were all of a stem rust susceptible nature. Four of those making up the 1946 samples were rust-resistant varieties whose quality is beyond question. These four new varieties now comprise a very substantial percentage of the cargoes, even in the case of the 2 Manitoba Northern Grade from Vancouver in 1946, where there was no apparent decrease in the number of varieties, as six of the less desirable varieties have been eliminated. The early criticism that Canadian export wheat was deteriorating is therefore not justified with the current list of wheats entering into the Overseas cargoes.

SUMMARY AND CONCLUSIONS

In 1925 fear was entertained by certain persons that the reputation of Canadian export wheat was in danger because of the high percentage of varieties of mediocre quality which it was believed were being grown at that time. In order to obtain factual information on this point, the Cereal Division, Department of Agriculture, Ottawa, in co-operation with the Board of Grain Commissioners, conducted exacting investigations extending over a twenty-three year period. During this period actual growing tests were made at Ottawa of two thousand, eight hundred and seventy-five samples collected by the Board of Grain Commissioners from this number of cargoes actually shipped from Pacific and Eastern Ports.

The data presented indicate clearly that at no time during the period under investigation was the percentage of undesirable varieties sufficiently great to have any possible effect on the general quality of our wheat.

While it is true that the number of undesirable varieties grown at one time was possibly greater than one would wish, yet the actual percentage of these was never very high. To-day, most of these varieties are practically extinct.

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APPENDIX

TABLE A1.—VARIETAL COMPOSITION OF 1 MANITOBA NORTHERN WHEAT BASED ON 455 CARGOES. EX. FORT WILLIAM, ONT. FOR YEARS 1931-1946, INCLUSIVE IN PER CENT

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1943	1944	1945	1946
Marquis	69.8	66.52	68.34	61.99	73.55	71.22	44.49	55.55	36.17	12.20	12.64	5.87	3.79	5.00	1.89
Garnet	2.4	1.67	2.93	2.41	1.33	0.46	1.14	0.26	0 13	0.28	0.22	0.09	0.03	0.08	0.02
Reward	6.7	8.59	10.32	8.13	6.07	10.85	12.38	2.57	1.49	1.52	1.04	1.05	0.46	0.13	0.16
Thatcher	—	—	—	—	—	—	0.23	11.48	38.47	37.91	39.67	49.70	68.73	80.22	74.21
Apex	—	—	—	—	—	—	—	—	0.35	20.61	17.47	14.15	9.72	2.02	2.13
Renown	—	—	—	—	—	—	—	—	2.58	3.10	5.32	5.45	2.54	1.28	1.48
Regent	—	—	—	—	—	—	—	—	—	0.77	3.54	8.16	3.71	1.37	19.06
Red Fife	2.2	3.07	0.34	0.91	0.08	1.25	4.60	0.39	—	0.07	0.45	0.24	0.03	—	—
Ruby	0.7	0.22	0.07	1.35	0.48	0.36	0.07	0.25	—	0.12	0.02	—	—	—	—
Red Bobs Sel.	2.1	2.12	3.00	2.89	1.79	1.51	26.46	20.83	14.93	16.64	13.50	10.75	5.75	7.25	0.15
Ceres	2.6	3.06	3.45	8.17	1.78	4.24	1.87	1.08	1.24	1.07	0.74	0.62	0.49	0.83	0.06
Early Red Fife	1.8	1.78	1.06	1.53	0.76	0.56	0.88	0.10	0.30	0.81	0.43	0.18	0.11	0.09	—
Type IC	8.0	6.79	5.86	5.63	7.57	6.29	3.84	4.44	3.21	3.57	2.74	1.88	1.26	1.07	0.20
Reliance	—	—	—	—	—	—	0.29	—	—	0.24	0.02	—	0.05	0.06	—
Canus	—	—	—	—	—	—	—	0.03	—	0.12	0.18	—	0.13	—	—
Kota	1.8	2.06	1.57	3.02	1.47	2.19	0.78	0.64	0.54	0.14	0.80	0.38	0.20	0.21	0.04
Pioneer	—	0.32	0.55	0.19	0.14	—	0.05	—	—	—	—	—	—	—	—
Coronation	—	—	—	—	—	—	—	0.03	—	0.06	0.12	0.44	0.30	—	—
Renfrew	0.10	0.11	0.06	0.10	0.01	0.02	0.02	0.03	—	—	—	—	—	—	—
Kitchener	0.33	0.10	0.10	0.02	—	0.03	0.02	—	—	—	—	—	—	—	—
Huron	0.37	0.01	0.01	0.53	0.10	0.03	0.08	0.03	—	—	—	0.02	—	—	—
Preston	0.03	0.17	0.29	0.10	—	0.11	0.08	0.03	—	—	—	0.03	—	—	—
Stanley	—	0.67	0.36	0.70	0.34	0.24	0.05	0.04	0.04	—	0.02	—	—	0.02	—
Parkers Sel.	0.16	0.36	0.21	1.19	0.83	0.16	0.10	0.54	0.01	0.04	—	0.02	—	—	0.02
Fishers Sel.	—	0.11	0.03	0.14	—	0.02	—	—	—	—	—	—	—	—	—
Prelude	—	0.01	0.05	—	0.03	—	0.03	—	—	—	—	—	—	—	—
Miscellaneous	0.28	0.46	0.40	0.01	1.70	0.14	1.93	0.87	0.17	0.36	0.12	0.82	2.61	0.13	—
Quality	—	—	0.05	0.07	—	—	—	—	—	—	—	—	—	—	—
Axminster	—	—	—	0.01	—	—	—	—	—	—	—	—	—	—	0.02
Ladoga	—	0.12	0.61	0.78	0.11	—	0.49	0.47	0.15	0.18	0.08	0.03	—	0.02	0.02
White Russian	0.03	0.15	0.02	0.08	0.11	0.08	0.02	0.01	—	0.04	—	—	0.01	—	—
Early Russian	—	0.15	—	0.13	0.03	0.03	—	—	—	—	—	—	—	—	—
Vermilion	—	—	—	0.02	—	—	—	—	—	—	—	—	0.01	—	—
Club or Red Club	0.09	0.04	0.04	0.03	0.02	—	—	0.01	0.04	0.04	—	—	—	—	—
Speltoid	0.45	0.05	0.06	0.08	0.02	0.11	0.05	0.07	—	—	0.02	0.02	0.03	0.04	—
Durum	0.03	0.01	0.02	0.03	—	0.03	—	0.04	—	—	—	—	—	—	0.11
Rye	—	—	—	—	—	—	—	0.03	—	—	—	—	—	—	—
6 Row barley	—	—	0.04	0.05	0.02	0.05	0.03	0.01	0.04	0.06	—	—	0.03	0.13	0.06
2 Row barley	—	—	0.05	0.01	—	0.01	—	—	0.02	0.02	—	—	—	0.02	—
Tame oats	—	0.01	0.02	0.03	—	—	—	0.01	0.13	0.02	—	—	—	—	—
Wild oats	0.01	0.03	0.03	0.03	—	—	—	—	—	—	—	—	0.01	0.02	—
Number of cargoes	30	50	50	50	25	25	25	25	25	25	25	25	25	25	25

TABLE A2.—VARIETAL COMPOSITION OF 2 MANITOBA NORTHERN WHEAT BASED ON 456 CARGOES. EX. FORT WILLIAM, ONT. FOR YEARS 1931-1946, INCLUSIVE IN PER CENT

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1943	1944	1945	1946
Marquis	40.93	41.18	44.63	40.02	72.22	55.62	34.34	44.03	25.94	9.50	10.42	2.95	0.22	4.92	2.24
Garnet	33.52	33.00	33.49	37.64	1.22	1.77	1.84	0.54	0.47	0.56	0.25	0.05	0.08	0.10	0.07
Reward	4.00	6.33	7.74	6.68	4.92	15.16	16.95	6.02	2.04	1.49	0.94	0.55	0.35	0.45	0.07
Thatcher	—	—	—	—	—	—	1.15	25.44	53.72	49.21	48.81	64.37	70.75	76.29	76.21
Apex	—	—	—	—	—	—	—	—	0.39	7.66	7.13	10.58	7.50	4.38	1.83
Renown	—	—	—	—	—	—	—	—	6.38	6.74	4.32	5.92	3.03	1.86	0.59
Regent	—	—	—	—	—	—	—	—	—	3.42	7.38	8.00	7.83	2.51	17.82
Red Fife	2.58	2.74	0.45	0.48	0.30	1.20	4.50	0.43	0.02	—	0.06	0.15	—	—	—
Ruby	0.92	0.31	0.10	0.35	0.47	0.41	0.10	0.16	—	0.01	—	0.01	0.01	—	—
Red Bobs Sel.	2.28	1.95	2.78	2.35	1.44	6.56	24.38	14.71	7.28	17.10	17.42	5.30	5.97	7.00	0.31
Ceres	2.57	2.37	2.16	1.78	1.74	7.67	5.58	1.14	1.05	0.71	0.33	0.66	0.50	0.60	0.17
Early Red Fife	3.08	1.40	0.56	0.90	1.78	0.46	1.21	0.52	0.19	0.34	0.46	0.06	0.06	0.08	—
Type IC	4.29	3.90	3.42	4.44	10.75	5.75	3.05	3.63	1.48	1.53	1.71	0.53	0.43	0.89	0.17
Reliance	—	—	—	—	—	—	—	0.04	0.02	0.28	0.06	0.03	0.02	0.08	—
Canus	—	—	—	—	—	—	0.70	—	—	0.15	0.06	—	0.02	—	0.02
Kota	1.09	1.76	1.46	1.27	1.75	3.55	1.61	0.82	0.39	0.11	0.31	0.24	0.03	0.05	—
Pioneer	—	0.64	3.42	0.12	0.07	0.04	—	—	—	—	—	—	—	—	0.08
Coronation	—	—	—	—	—	—	—	0.03	0.09	0.01	0.13	0.04	0.50	—	—
Renfrew	0.88	0.79	0.25	0.08	0.06	0.04	—	0.04	—	—	—	—	—	—	—
Kitchener	0.24	0.15	0.04	0.01	0.16	—	0.04	—	—	—	—	—	—	—	0.02
Huron	0.90	0.03	0.04	0.53	0.24	0.06	0.12	0.09	0.02	—	—	—	—	—	—
Preston	0 04	0.49	0.27	0.03	0.03	0.26	0.26	0.03	—	0.17	0.04	—	—	—	—
Stanley	0.41	1.09	0.50	0.88	0.30	0.31	0.12	0.16	0.04	0.03	—	0.06	0.03	0.01	—
Parkers Sel.	0.39	0.23	0.47	1.25	1.19	0.39	0.20	0.70	0.02	0.11	—	0.03	—	—	0.02
Fishers Sel.	—	0.14	—	0.13	—	0.07	—	—	0.02	—	—	—	—	—	—
Prelude	—	—	0.03	0.03	—	0.04	—	—	—	—	—	—	—	—	—
Miscellaneous	1.01	0.45	0.15	—	0.78	0.13	3.10	0.46	0.11	0.36	—	0.32	1.52	0.20	—
Quality	0.05	0.01	0.01	—	—	—	—	—	—	—	—	—	—	—	—
Axminster	—	—	—	0.01	—	—	—	—	—	—	—	—	—	—	—
Ladoga	—	0.61	0.38	0.33	0.34	—	0.41	0.36	0.09	0.17	0.06	—	—	0.03	0.10
White Russian	0.22	0.13	0.03	0.24	0.04	0.04	0.04	—	—	0.06	0.02	—	0.01	0.01	—
Early Russian	—	0.05	0.03	0.12	0.03	0.02	0.02	0.03	—	—	—	—	—	—	0.02
Vermilion	0.01	—	—	0.05	—	—	—	—	—	—	—	—	—	—	—
Club or Red Club	0.10	0.09	0.16	0.07	0.01	—	0.04	—	—	0.06	0.02	—	—	—	—
Speltoid	0.22	0.07	0.02	0.04	0.01	0.20	0.05	0.06	0.04	0.02	0.02	0.32	0.08	—	—
Durum	0.01	0.04	—	—	—	0.06	0.04	0.07	—	—	—	0.02	0.01	—	0.07
Rye	—	—	—	—	—	—	—	—	—	0.02	—	—	—	—	0.02
6 Row Barley	0.01	0.11	0.05	0.09	0.04	0.15	0.11	0.01	0.06	0.04	0.02	—	0.03	0.30	0.12
2 Row Barley	—	—	0.05	—	0.04	0.04	0.02	—	0.02	0.02	—	0.01	—	0.07	—
Tame oats	—	—	0.04	0.08	0.03	0.02	—	0.01	0.11	0.06	0.02	—	—	—	—
Wild oats	—	0.01	0.01	0.01	—	—	—	—	—	0.02	—	—	—	0.07	—
Number of cargoes	31	50	50	50	25	25	25	25	25	25	25	25	25	25	25

TABLE A3.—VARIETAL COMPOSITION OF 3 MANITOBA NORTHERN WHEAT BASED ON 454 CARGOES. EX. FORT WILLIAM, ONT. FOR YEARS 1931-1946, INCLUSIVE IN PER CENT

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1943	1944	1945	1946
Marquis	38.88	42.36	51.34	33.91	53.48	23.61	7.45	37.50	23.21	6.06	6.66	1.43	0.27	3.25	3.51
Garnet	25.01	27.02	22.55	38.97	24.13	58.31	70.75	1.60	0.70	1.18	0.48	0.07	0.23	0.43	0.06
Reward	3.59	8.64	6.80	8.77	5.82	5.93	4.64	6.41	2.27	1.65	0.50	0.41	0.50	0.53	0.05
Thatcher	—	—	—	—	—	—	0.21	22.12	45.88	54.76	58.86	72.44	51.73	64.37	82.65
Apex	—	—	—	—	—	—	—	—	0.45	5.18	10.45	9.06	11.89	11.33	1.93
Renown	—	—	—	—	—	—	—	—	5.22	5.54	3.41	3.95	4.43	3.11	0.79
Regent	—	—	—	—	—	—	—	—	—	2.95	6.79	5.78	6.43	3.82	7.58
Red Fife	3.90	1.09	0.68	0.60	0.55	0.74	0.21	0.95	—	0.19	0.02	0.02	0.04	0.01	—
Ruby	2.94	0.33	0.03	0.83	0.12	0.45	0.42	0.11	0.06	0.02	—	0.05	—	0.14	—
Red Bobs Sel.	4.13	3.34	2.79	4.13	1.66	3.21	8.16	21.05	18.31	19.01	10.97	3.86	21.26	9.95	1.14
Ceres	2.92	5.74	3.66	1.62	1.75	1.69	1.70	2.42	0.52	0.64	0.13	0.88	0.46	0.65	0.54
Early Red Fife	2.18	0.69	1.34	1.04	1.44	0.62	0.13	0.72	0.27	0.51	0.46	0.18	0.18	0.08	0.03
Type IC	5.40	3.45	6.46	5.34	6.80	3.12	0.87	3.18	1.10	0.96	0.46	0.85	1.10	0.91	0.74
Reliance	—	—	—	—	—	—	0.03	—	—	0.15	0.04	0.02	—	0.07	0.02
Camus	—	—	—	—	—	—	—	—	—	—	0.08	—	—	—	—
Kota	0.92	0.306	2.42	1.00	0.95	1.13	0.95	·0.70	0.68	0.10	0.15	0.12	0.03	0.05	0.06
Pioneer	0.61	0.19	0.63	0.23	0.06	0.10	0.23	—	—	0.06	—	—	—	—	—
Coronation	—	—	—	—	—	—	—	0.40	0.64	0.06	0.36	0.02	0.93	0.01	0.09
Renfrew	0.97	0.65	0.06	0.04	0.04	—	—	0.10	—	—	—	—	—	—	—
Kitchener	0.95	0.05	0.19	0.01	0.06	—	—	—	—	—	—	—	—	—	—
Huron	0.80	0.11	0.13	0.34	0.12	—	0.19	0.11	0.04	0.04	—	0.02	—	—	—
Preston	0.07	0.40	0.77	0.12	0.07	0.26	0.06	0.19	—	0.13	0.04	—	0.01	—	—
Stanley	1.13	0.75	0.07	0.53	0.22	0.24	0.30	0.14	0.14	0.09	—	—	—	—	—
Parkers Sel.	1.72	0.44	0.01	1.59	1.51	0.21	0.13	0.65	—	—	—	—	—	—	—
Quality	0.23	—	0.30	—	—	—	—	—	—	—	—	—	—	—	—
Prelude	—	0.01	0.03	0.03	0.03	—	0.03	0.01	—	—	—	—	—	—	—
Fishers	0.06	0.06	—	0.05	0.01	—	—	0.02	—	—	—	—	—	—	—
Miscellaneous	1.56	0.42	0.10	—	0.38	0.12	3.22	0.62	0.14	0.28	0.04	0.71	0.27	0.63	—
Ladoga	0.05	0.60	0.28	0.54	0.50	—	0.02	0.41	0.16	0.04	—	—	—	0.10	0.02
White Russian	1.00	0.11	0.03	0.09	0.07	—	—	0.04	—	0.10	—	—	—	—	—
Early Russian	0.33	0.04	—	0.04	0.03	—	—	—	—	—	—	—	—	—	—
Java	0.07	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Broatch Sel.	—	—	—	—	—	—	—	—	—	—	—	—	—	0.01	—
Club or Red Club	0.05	0.04	0.06	0.05	—	0.02	0.02	0.01	—	—	—	—	0.01	—	—
Marquillo	—	—	—	—	—	0.05	—	—	—	—	—	—	—	—	—
Speltoid	0.39	0.13	0.01	0.02	0.03	0.06	0.05	0.07	0.04	0.09	0.02	0.02	0.07	0.05	—
Durum	0.05	0.06	0.14	0.03	0.03	—	0.03	0.03	0.06	—	—	—	0.03	0.03	0.08
Rye	—	—	—	—	—	—	0.17	—	0.02	—	—	—	—	0.07	—
6 Row barley	0.02	0.14	0.09	0.08	0.03	0.05	0.02	0.02	0.04	0.09	0.04	0.08	0.01	0.29	0.11
2 Row barley	0.02	0.01	0.01	—	—	0.02	—	—	0.02	0.02	—	0.02	0.01	0.01	0.06
Tame oats	—	0.02	0.04	0.01	—	0.02	—	—	0.02	0.06	0.02	—	—	—	—
Wild oats	0.02	—	0.01	0.01	—	0.03	—	0.01	—	—	—	—	0.01	—	—
Number of cargoes	31	50	50	50	25	25	25	25	25	25	25	25	25	25	25

TABLE A4.—VARIETAL COMPOSITION OF 4 MANITOBA NORTHERN WHEAT BASED ON 177 CARGOES. EX. FORT WILLIAM, ONT. FOR YEARS 1938-1946, INCLUSIVE IN PER CENT

	1938	1939	1940	1941	1943	1944	1945	1946
Marquis	55.22	53.83	20.31	2.97	6.06	0.04	11.55	4.75
Garnet	3.70	1.65	3.53	0.68	2.15	0.58	0.63	0.17
Reward	8.22	1.54	3.22	0.37	0.68	0.47	0.62	—
Thatcher	7.77	20.76	40.46	62.54	44.56	48.72	65.36	80.75
Apex	—	—	—	11.55	9.58	13.34	1.41	1.96
Renown	—	—	2.44	4.58	4.10	3.00	2.56	0.64
Regent	—	—	0.57	8.61	5.31	9.35	3.90	5.23
Red Fife	0.76	0.06	0.04	0.05	—	—	0.02	—
Ruby	0.10	—	0.13	—	0.02	—	—	0.05
Red Bobs Sel.	10.41	17.32	23.76	6.90	21.42	22.05	9.36	3.75
Ceres	5.78	0.53	0.57	0.45	0.45	0.57	0.88	0.31
Early Red Fife	0.59	0.20	0.52	0.08	0.19	0.27	0.10	0.02
Type IC	3.91	1.54	1.83	0.39	1.83	0.74	0.87	1.15
Reliance	0.05	0.04	0.48	—	0.02	—	0.03	—
Canus	—	—	—	—	0.06	0.02	—	—
Kota	1.17	0.94	0.08	0.03	0.15	0.08	0.07	0.09
Pioneer	—	—	0.13	—	0.02	—	—	—
Coronation	—	—	0.04	0.39	0.47	0.20	—	0.29
Renfrew	0.06	—	—	—	—	—	—	—
Huron	0.03	0.07	—	—	0.04	0.02	0.05	—
Preston	0.12	0.11	—	0.05	—	0.02	—	0.03
Stanley	0.10	—	0.17	0.10	0.04	—	—	—
Parkers Sel.	0.54	—	—	—	0.04	—	0.02	—
Prelude	—	—	0.04	—	—	—	—	—
Miscellaneous	0.52	0.55	0.83	0.03	2.49	0.18	2.17	—
Ladoga	0.47	—	—	0.03	0.02	0.04	—	0.10
White Russian	0.06	—	0.35	—	0.02	—	0.01	—
Club or Red Club	0.03	0.02	—	—	—	—	—	—
Speltoid	0.07	—	—	0.03	0.02	0.10	0.08	—
Durum	0.05	0.29	0.04	0.03	0.02	0.06	—	0.07
Rye	0.01	0.02	—	0.03	0.04	—	—	0.02
6 Row barley	0.03	0.08	0.26	0.03	0.13	0.12	0.25	0.07
2 Row barley	—	—	0.09	0.03	0.02	—	0.02	0.09
Tame oats	0.01	0.21	—	0.05	—	—	—	—
Wild oats	0.01	—	—	—	—	—	—	—
Number of cargoes	25	22	11	20	25	25	25	24

TABLE A5.—VARIETAL COMPOSITION OF 1 MANITOBA NORTHERN WHEAT BASED ON 404 CARGOES. EX. VANCOUVER, B.C. FOR THE YEARS 1931-1946, INCLUSIVE IN PER CENT

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1943	1944	1945	1946
Marquis	49.72	51.60	53.78	53.75	54.09	51.32	44.36	31.81	32.65	13.73	15.64	3.69	0.29	19.22	8.99
Garnet	3.83	4.26	2.87	2.73	1.11	1.05	1.17	0.86	0.93	1.17	1.25	0.67	0.19	0.46	0.64
Reward	4.38	9.58	10.72	6.05	4.47	3.46	2.49	1.64	2.43	2.38	3.01	2.26	2.26	1.07	0.23
Thatcher	—	—	—	—	—	—	0.11	0.44	1.90	5.21	5.86	8.56	22.34	15.10	27.90
Apex	—	—	—	—	—	—	—	—	—	—	0.11	8.64	16.14	0.04	1.98
Renown	—	—	—	—	—	—	—	—	—	—	0.06	3.25	1.08	0.32	0.43
Regent	—	—	—	—	—	—	—	—	—	—	—	2.60	5.31	1.25	3.17
Red Fife	4.34	2.60	0.69	0.52	0.30	1.50	3.05	0.51	0.04	—	—	0.03	—	—	0.06
Ruby	0.96	0.44	0.13	0.19	0.15	0.41	0.02	0.01	—	0.10	—	0.03	—	0.04	—
Red Bobs Sel.	17.65	20.25	21.31	25.24	26.23	32.69	39.58	54.91	55.86	71.46	71.54	65.10	47.04	57.65	52.85
Ceres	0.58	0.62	0.39	0.32	0.09	0.45	0.08	0.13	0.13	0.31	—	0.38	1.67	0.83	0.72
Early Red Fife	1.27	0.54	0.47	0.76	0.38	0.46	0.33	0.10	0.44	0.51	0.06	0.18	0.49	0.30	0.13
Type IC	9.51	6.68	6.72	6.84	8.58	6.60	4.90	4.13	3.32	3.14	1.02	1.93	0.94	0.93	1.09
Reliance	—	—	—	—	—	—	0.06	0.05	—	0.31	0.06	0.12	0.10	0.06	0.23
Canus	—	—	—	—	—	—	—	—	—	—	0.06	—	—	—	—
Kota	0.87	0.87	0.75	0.62	0.82	0.67	0.40	0.91	0.62	0.31	0.23	0.18	0.19	0.12	0.23
Pioneer	0.11	0.11	0.23	0.08	—	0.02	0.05	0.07	—	—	—	—	—	—	—
Coronation	—	—	—	—	—	—	—	—	—	—	0.11	0.06	1.18	—	0.77
Renfrew	0.87	0.34	0.07	0.03	0.02	—	—	0.07	—	—	—	—	—	—	—
Kitchener	0.96	0.31	0.33	0.04	0.51	0.02	0.06	0.08	—	—	—	—	—	—	—
Huron	0.49	0.03	0.24	0.11	—	0.02	0.02	0.01	0.04	—	—	0.06	0.19	0.02	0.02
Preston	0.06	0.10	0.20	0.07	0.06	0.24	0.05	0.01	0.04	—	0.06	0.03	0.09	—	0.09
Stanley	0.20	0.18	0.20	0.56	0.04	0.17	0.14	0.05	—	0.41	0.06	0.09	—	0.04	0.02
Parkers Sel.	0.73	0.48	0.09	1.28	1.23	0.34	—	0.31	—	0.10	0.11	—	—	0.02	—
Fishers	0.14	—	0.01	0.19	—	0.03	—	—	—	—	—	—	—	—	—
Prelude	—	—	0.02	0.01	0.02	—	—	—	—	—	—	—	—	—	—
Quality	0.06	—	0.02	0.01	—	—	—	—	—	—	—	—	—	—	—
Miscellaneous	2.49	0.52	0.11	0.01	0.62	0.12	2.62	2.90	1.23	0.62	—	1.96	0.19	2.50	—
Axminster	—	—	—	0.02	—	—	—	—	—	—	—	—	—	—	—
Ladoga	0.03	0.09	0.28	0.35	0.30	—	0.37	0.20	—	—	—	—	—	—	0.04
White Russian	0.34	—	0.01	0.07	0.04	0.07	0.02	—	—	0.03	—	0.03	—	—	0.06
Early Russian	0.15	0.03	—	0.01	—	0.05	0.05	0.06	—	—	—	0.03	—	—	0.04
Percy	—	—	0.01	—	0.02	—	—	—	—	—	—	—	—	—	—
Java	—	—	0.01	—	—	—	—	—	—	—	—	—	—	—	—
Broatch Sel.	—	—	0.01	—	—	—	—	—	—	—	—	—	—	—	—
Club or Red Club	—	0.14	0.01	0.06	0.02	—	—	0.01	—	—	—	0.06	—	—	—
Speltoid	0.15	0.13	—	0.05	—	0.07	0.05	0.03	—	0.03	0.06	0.03	0.19	0.08	—
Durum	—	0.01	—	0.01	0.02	—	—	—	—	—	—	—	—	—	—
6 Row barley	0.01	0.04	0.07	0.01	0.02	—	0.02	—	—	0.10	0.06	—	—	—	0.02
2 Row barley	—	—	0.02	—	—	—	—	—	—	—	—	—	—	0.06	—
Tame oats	0.01	—	0.04	0.01	—	—	—	—	0.31	0.03	—	—	—	—	—
Wild oats	0.03	—	0.01	—	—	—	—	0.03	—	—	—	—	—	—	—
Number of cargoes	30	50	50	50	25	25	25	25	13	16	14	25	6	25	25

TABLE A6.—VARIETAL COMPOSITION OF 2 MANITOBA NORTHERN WHEAT BASED ON 384 CARGOES. EX. VANCOUVER, B.C. FOR THE YEARS 1931-1946, INCLUSIVE IN PER CENT

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1943	1944	1945	1946
Marquis	6.86	16.13	12.63	9.19	46.75	37.43	31.58	24.79	21.64	10.57	43.65	4.69	1.29	12.48	12.88
Garnet	65.35	64.82	66.80	74.10	1.68	2.72	3.32	1.91	1.46	2.41	0.48	1.43	0.98	1.47	0.46
Reward	2.14	5.06	6.37	4.10	5.16	7.57	7.86	4.79	6.14	3.75	1.46	3.17	0.68	0.55	0.33
Thatcher	—	—	—	—	—	—	0.12	0.18	1.22	2.08	3.88	10.74	17.91	29.65	31.22
Apex	—	—	—	—	—	—	—	—	0.19	—	—	6.58	11.69	0.01	0.48
Renown	—	—	—	—	—	—	—	—	—	—	—	2.02	0.55	0.21	0.12
Regent	—	—	—	—	—	—	—	—	—	—	—	2.89	1.85	0.97	1.97
Red Fife	4.93	0.93	0.34	0.24	0.24	0.96	2.39	0.94	0.29	—	—	0.12	—	—	0.08
Ruby	0.13	0.43	0.20	0.23	0.06	0.89	0.09	0.07	0.15	0.08	—	0.03	—	0.04	—
Red Bobs Sel.	9.36	6.65	7.56	6.81	33.37	41.14	44.91	59.73	61.79	75.68	45.59	59.31	61.84	50.49	48.25
Ceres	0.78	0.65	0.10	0.46	0.52	0.15	0.17	0.27	0.39	0.41	—	0.78	—	0.69	0.46
Early Red Fife	1.09	0.44	0.36	0.42	0.22	0.68	0.82	0.50	0.43	0.50	0.97	0.81	0.55	0.29	0.08
Type IC	3.45	1.59	2.26	1.51	7.23	6.64	4.21	2.45	4.19	1.83	1.46	1.40	1.41	1.76	2.05
Reliance	—	—	—	—	0.04	—	0.05	0.09	0.24	0.33	—	0.09	0.25	0.04	0.08
Kota	0.20	0.41	0.55	0.25	9.50	0.56	0.43	0.61	0.15	0.17	—	0.12	—	0.04	0.27
Pioneer	0.02	0.30	0.25	0.22	—	0.02	0.05	0.03	—	—	—	0.09	—	—	0.02
Coronation	—	—	—	—	—	—	—	—	—	—	—	—	0.12	—	0.37
Renfrew	0.91	0.14	0.03	0.16	0.06	0.02	—	—	—	—	—	—	—	—	0.04
Kitchener	0.81	0.19	0.13	0.03	0.37	0.06	0.04	—	—	0.17	—	—	—	—	0.02
Huron	0.76	0.06	0.59	0.19	0.02	—	0.15	0.09	0.05	—	—	0.22	0.37	0.03	0.02
Preston	0.24	0.63	0.15	0.08	0.02	0.25	0.31	0.13	0.09	—	0.49	0.06	0.06	0.06	0.02
Stanley	—	0.33	0.46	0.23	0.14	0.28	0.24	0.11	—	0.25	—	0.22	0.30	0.19	0.06
Parkers Sel.	1.06	2.70	0.07	0.24	0.89	0.17	0.02	0.66	—	—	0.97	0.09	—	0.03	0.02
Fishers	—	—	0.02	0.02	—	0.02	—	—	—	—	—	—	—	—	—
Prelude	—	—	0.01	0.02	—	—	—	0.05	—	—	—	—	—	—	—
Quality	—	0.01	0.01	0.01	—	—	—	—	—	—	—	—	—	—	—
Miscellaneous	1.00	0.39	0.15	0.04	1.81	0.19	0.65	2.04	1.25	1.58	0.49	4.97	—	0.68	—
Axminster	—	—	0.08	0.07	—	—	—	—	—	—	—	—	—	—	—
Ladoga	0.32	0.01	0.39	0.03	0.30	—	0.37	0.22	0.05	0.08	—	—	0.06	0.06	0.21
White Russian	0.02	0.04	—	0.09	0.10	0.09	0.07	—	—	—	—	0.03	—	0.05	0.04
Early Russian	—	0.07	—	0.05	—	0.06	0.09	0.05	—	—	—	—	—	—	0.04
Club or Red Club	0.02	0.12	0.16	0.03	—	—	0.15	0.03	0.05	—	—	—	—	—	—
Speltoid	0.11	0.08	0.03	0.06	0.02	0.06	0.07	0.03	—	0.08	0.49	0.09	0.06	0.03	—
Durum	—	0.05	—	—	—	—	0.03	—	—	—	—	—	—	—	—
Rye	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.02
6 Row barley	0.17	0.09	0.13	0.11	0.02	0.04	0.02	0.05	0.15	—	—	0.03	—	0.11	0.04
2 Row barley	0.07	0.01	0.01	0.08	—	—	—	0.07	—	—	—	—	—	—	—
Tame oats	0.16	—	0.02	0.01	—	—	—	—	0.05	—	—	0.03	—	—	—
Wild oats	0.01	—	0.03	—	—	—	—	—	—	—	—	—	—	—	—
Number of cargoes	29	50	50	50	25	25	25	25	11	7	2	25	10	24	25

TABLE A7.—VARIETAL COMPOSITION OF 3 MANITOBA NORTHERN WHEAT BASED ON 367 CARGOES. EX. VANCOUVER, B.C. FOR YEARS 1931-1946, INCLUSIVE

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1943	1945	1946
Marquis	33.05	27.71	17.81	14.97	25.23	6.46	5.29	19.57	23.53	14.00	11.24	3.19	6.68	8.60
Garnet	30.07	43.66	53.41	57.65	42.08	75.03	77.64	3.32	3.62	3.28	3.09	1.22	2.54	1.32
Reward	2.45	5.97	8.91	7.59	5.66	4.26	2.59	4.06	4.99	3.28	2.25	0.80	0.30	0.12
Thatcher	—	—	—	—	—	—	—	0.72	0.22	4.42	2.81	16.17	37.51	40.02
Apex	—	—	—	—	—	—	—	—	—	—	0.56	5.31	0.16	3.66
Renown	—	—	—	—	—	—	—	—	—	—	—	1.12	0.23	0.10
Regent	—	—	—	—	—	—	—	—	—	—	—	2.46	0.95	1.12
Red Fife	3.63	1.97	0.19	0.25	—	0.17	0.12	0.51	—	—	0.56	0.06	—	—
Ruby	0.11	0.63	0.27	0.44	0.06	0.31	0.12	0.03	0.05	0.76	—	0.04	0.02	0.02
Red Bobs Sel.	12.59	11.92	11.89	11.68	17.30	9.64	6.92	58.27	56.55	62.97	75.59	61.96	47.45	42.23
Ceres	0.78	0.29	0.29	0.37	0.47	0.34	0.10	0.72	1.43	0.50	—	0.24	0.64	0.40
Early Red Fife	1.86	0.89	0.44	0.40	0.47	0.29	0.07	1.03	1.26	1.14	0.84	0.46	0.25	0.14
Type IC	5.95	3.94	2.76	3.57	3.19	1.56	0.81	4.08	3.78	3.03	1.40	0.60	1.18	1.58
Reliance	—	—	—	0.01	0.14	—	—	0.14	—	—	—	0.02	0.25	0.03
Canus	—	—	—	—	—	—	—	—	—	0.25	—	0.08	0.07	—
Kota	1.48	0.47	0.61	0.32	0.43	0.24	0.10	0.77	0.38	1.01	—	—	0.02	—
Pioneer	0.03	0.38	0.40	0.15	0.08	0.01	0.07	—	—	—	—	—	—	0.03
Coronation	—	—	—	—	—	—	—	—	—	—	—	0.90	—	0.24
Renfrew	0.45	0.21	—	0.08	0.02	—	—	0.05	—	—	—	—	—	—
Kitchener	1.21	0.11	0.06	0.03	0.02	—	—	0.01	—	0.13	—	—	—	—
Huron	2.85	0.02	0.53	0.37	0.02	—	0.07	0.15	0.16	—	—	—	0.05	0.02
Preston	0.20	0.53	0.18	0.18	0.39	0.56	0.19	0.47	0.60	1.00	—	0.08	0.05	0.05
Stanley	—	0.19	0.72	0.21	0.22	0.26	0.12	0.22	0.10	1.14	0.28	0.14	0.02	0.02
Parkers Sel.	0.34	0.10	0.16	1.05	0.43	0.02	0.02	0.44	—	0.25	0.28	0.04	0.06	0.03
Fishers	—	—	0.01	0.01	—	—	—	—	—	—	—	—	—	—
Prelude	—	0.03	0.02	0 01	—	—	0.03	—	—	—	—	—	—	—
Quality	0.04	0.01	0.02	—	—	—	—	—	—	—	—	—	—	—
Miscellaneous	1.52	0.40	0.37	—	3.61	0.14	5.58	5 12	2.95	2.27	—	5.07	1.27	—
Axminster	—	—	0.01	0.04	—	—	—	—	—	—	—	—	—	—
Pacific B. Stem	—	—	—	0.07	—	—	—	—	—	—	—	—	—	—
Ladoga	0.05	0.15	0.21	0.08	—	—	—	—	—	0.13	—	—	0.05	0.07
White Russian	0.58	0.06	—	0.13	0.06	0.09	0.02	0.01	—	0.13	—	—	0.05	0.03
Early Russian	0.05	0.03	—	0.08	—	0.07	—	0.03	—	—	—	—	—	—
Percy	—	—	—	0.01	—	—	—	—	—	—	—	—	—	—
Vermilion	—	—	—	0.01	—	—	—	—	—	—	—	—	—	—
Club or Red Club	0.31	0.16	0.13	0.10	0.02	0.02	0.03	—	0.05	—	—	—	—	—
Speltoid	0.29	0.04	0.01	0.01	0.02	0.22	0.02	0.03	—	—	0.28	0.02	0.05	—
Durum	—	—	—	0.11	—	—	—	—	—	—	—	—	—	—
6 Row barley	0.04	0.11	0.10	0.07	0.04	—	0.05	0.12	0.11	0.25	0.28	—	0.09	0.12
2 Row barley	—	0.02	0.01	—	0.04	—	—	0.01	—	—	—	—	—	0.02
Tame oats	0.01	—	0.02	0.02	—	—	0.02	0.01	0.16	—	—	—	—	—
Wild oats	0.05	0.01	0.01	0.01	—	—	—	—	—	—	—	—	0.05	—
Number of cargoes	30	50	50	50	25	25	25	25	10	5	2	25	20	25

TABLE A8.—VARIETAL COMPOSITION OF 4 MANITOBA NORTHERN WHEAT BASED ON 46 CARGOES. EX. VANCOUVER, B.C. FOR YEARS 1938, 1943 AND 1946 ONLY IN PER CENT

	1938	1943	1946
Marquis	13.63	—	8.25
Garnet	10.77	5.08	2.68
Reward	6.16	0.22	0.11
Thatcher	0.19	19.45	46.50
Apex	—	3.54	6.93
Renown	—	3.09	0.50
Regent	—	7.07	1.02
Red Fife	0.40	—	0.07
Ruby	0.15	—	—
Red Bobs Sel.	58.79	55.47	31.19
Ceres	0.30	0.66	0.15
Early Red Fife	0.99	0.88	0.07
Type IC	2.99	0.88	1.67
Reliance	0.59	—	0.04
Canus	0.24	—	—
Kota	0.34	—	0.24
Pioneer	—	1.55	—
Coronation	—	—	0.30
Kitchener	0.03	0.22	—
Huron	0.15	—	—
Preston	0.63	—	—
Stanley	0.40	—	—
Parkers Sel.	0.51	—	—
Miscellaneous	1.88	1.55	—
Ladoga	0.13	—	0.02
White Russian	0.15	—	—
Early Russian	0.01	—	—
Club or Red Club	0.07	—	—
Speltoid	0.03	—	—
6 Row barley	0.24	—	0.11
2 Row barley	—	0.22	0.02
Tame oats	0.03	—	—
Wild oats	0.01	—	—
Number of cargoes	25	2	0.19

TABLE A9.—VARIETAL COMPOSITION OF 1 MANITOBA NORTHERN WHEAT BASED ON 26 CARGOES. EX. CHURCHILL, MAN. FOR YEARS 1935*-1946, INCLUSIVE IN PER CENT

	1935	1936	1937	1938	1939	1946
Marquis	64.71	69.03	63.55	60.42	65.63	16.34
Garnet	1.53	0.80	2.20	0.27	0.84	0.58
Reward	9.10	8.80	4.03	5.33	2.09	5.46
Thatcher	—	—	—	22.82	17.97	62.62
Apex	—	—	—	—	—	4.37
Renown	—	—	—	—	—	0.17
Regent	—	—	—	—	—	3.88
Red Fife	0.73	0.27	6.41	—	—	0.08
Ruby	0.37	0.13	—	0.13	—	—
Red Bobs Sel.	1.04	1.80	2.20	4.78	3.76	2.48
Ceres	1.40	1.20	—	0.68	1.04	0.41
Early Red Fife	1.65	3.00	4.40	0.82	0.42	0.41
Type IC	9.58	12.00	10.44	3.28	4.60	2.64
Reliance	—	0.27	0.37	—	—	0.17
Canus	—	—	—	0.27	—	0.08
Kota	0.37	1.53	1.65	—	0.63	0.08
Pioneer	0.18	0.06	—	—	—	—
Coronation	—	—	—	—	—	0.17
Kitchener	0.12	—	—	—	—	—
Huron	0.06	—	—	—	—	—
Preston	0.24	0.20	—	—	—	—
Stanley	0.37	0.40	—	0.13	0.21	—
Parkers Sel.	1.40	0.13	—	0.27	—	—
Miscellaneous	5.00	—	3.29	0.41	2.30	—
Ladoga	—	—	0.74	0.13	—	—
White Russian	2.01	0.07	0.18	—	—	—
Early Russian	0.06	0.13	—	—	—	—
Club or Red Club	0.06	—	—	—	—	—
Speltoid	—	0.07	—	—	—	—
Wild oats	—	—	—	0.13	—	—
Number of cargoes	7	6	2	3	2	6

* Years 1940, 1941, 1942, 1943, 1944, 1945 not represented.

TABLE A10.—VARIETAL COMPOSITION OF 2 MANITOBA NORTHERN WHEAT BASED ON 34 CARGOES. EX. CHURCHILL, MAN. FOR YEARS 1935*-1946, INCLUSIVE IN PER CENT

	1935	1936	1937	1938	1939	1943	1946
Marquis	55.21	66.13	45.39	35.69	35.75	1.45	10.92
Garnet	11.71	3.64	9.62	2.49	1.86	0.89	0.53
Reward	12.89	9.07	4.23	10.43	7.62	10.73	3.69
Thatcher	—	—	—	32.61	32.80	49.43	73.49
Apex	—	—	—	—	0.22	11.40	2.11
Renown	—	—	—	—	—	5.59	0.68
Regent	—	—	—	—	—	3.97	1.20
Red Fife	0.16	0.13	9.61	0.47	—	—	0.08
Ruby	0.55	0.13	—	0.23	0.07	0.06	—
Red Bobs Sel.	1.90	1.32	0.39	10.31	8.59	6.26	4.30
Ceres	1.11	2.98	0.39	1.06	1.12	1.23	0.23
Early Red Fife	2.93	2 65	6.50	0.23	3.58	3.75	0.08
Type IC	7.59	10.26	13.46	3.79	4.18	1.78	1.66
Reliance	—	—	0.39	—	0.22	0.34	0.08
Kota	0.87	1.59	1.16	—	1.04	0.17	0.08
Coronation	—	—	—	—	—	—	0.15
Renfrew	—	0.06	—	—	—	—	—
Kitchener	0.31	—	—	—	—	—	—
Huron	—	—	—	—	0.07	—	—
Preston	0.47	0.53	—	—	0.37	0.06	0.08
Stanley	0.40	0.33	1.93	—	0.07	0.11	—
Parkers Sel.	0.95	0.53	—	—	—	—	—
Quality	—	—	—	—	0.07	—	—
Miscellaneous	2.61	0.19	3.84	0.35	1.79	2.01	—
Ladoga	0.16	—	1.54	0.11	—	0.06	0.38
White Russian	—	0.13	0.77	0.11	—	—	—
Early Russian	0.08	0.06	—	—	—	—	—
Percy	—	—	0.39	—	—	—	—
Club or Red Club	—	—	—	—	—	0.06	—
Vermilion	0.08	—	—	—	—	—	—
Speltoid	—	0.20	0.39	0.59	—	0.50	—
Rye	—	—	—	—	0.07	—	—
6 Row Barley	—	—	—	0.23	0.15	0.08	—
2 Row Barley	—	—	—	—	—	0.08	—
Tame oats	—	—	—	—	0.37	0.08	—
Number of cargoes	6	6	1	2	6	7	6

* 1940, 1941, 1942, 1944 and 1945 not represented.

TABLE A11.—VARIETAL COMPOSITION OF 3 MANITOBA NORTHERN WHEAT BASED ON 19 CARGOES. EX CHURCHILL, MAN. FOR THE YEARS 1935*-1946, INCLUSIVE

	1935	1936	1937	1938	1939	1943	1946
Marquis	45.15	41.59	25.72	42.70	47.56	3.01	2.64
Garnet	28.29	36.14	41.39	6.30	3.22	2.58	—
Reward	8.43	6.81	11.11	7.70	10.32	12.69	—
Thatcher	—	—	—	15.75	13.87	30.10	89.73
Apex	—	—	—	—	—	17.63	2.23
Renown	—	—	—	—	—	10.97	0.40
Regent	—	—	—	—	—	3.66	1.20
Red Fife	—	0.79	3.70	1.40	—	—	—
Ruby	—	—	—	—	0.08	—	—
Red Bobs Sel.	1.20	1.00	1.02	7.70	9.00	4.36	1.20
Ceres	0.60	0.65	0.83	5.25	2.89	2.37	—
Early Red Fife	5.42	3.15	2.68	1.14	2.36	4.09	—
Type IC	3.61	6.96	4.53	3.15	4.54	1.72	1.02
Reliance	—	—	0.21	—	0.08	0.65	—
Pioneer	1.20	1.08	1.24	0.35	1.07	0.43	—
Coronation	1.80	—	0.41	—	—	—	—
Renfrew	—	—	—	—	—	0.21	—
Kitchener	—	—	—	—	—	—	1.62
Huron	—	0.22	—	—	0.17	0.43	—
Preston	0.60	0.43	0.21	0.35	—	0.21	—
Stanley	0.60	—	0.62	0.35	—	—	—
Parkers Sel.	—	0.43	—	—	—	—	—
Miscellaneous	2.41	0.07	6.12	7.00	4.12	4.73	—
Early Russian	0.60	0.21	—	—	—	—	—
Club or Red Club	—	—	—	—	—	0.21	—
Speltoid	—	0.43	—	—	—	—	—
6 Row Barley	—	—	0.21	0.35	0.17	—	—
Tame oats	—	—	—	—	0.33	—	—
Number of cargoes	1	6	2	1	5	2	2

* Years 1940, 1941 and 1942 not represented.

TABLE A12.—VARIETAL COMPOSITION OF 1°, 2° AND 3° MANITOBA NORTHERN WHEAT. EX. MONTREAL, P.Q. FOR SEASON 1935

	1° 1935	2° 1935	3° 1935
Marquis	63.12	63.59	46.82
Garnet	1.35	5.90	26.25
Reward	9.70	9.23	9.04
Red Fife	0.86	2.21	0.16
Ruby	0.55	0.25	0.49
Red Bobs Sel.	2.54	2.09	1.98
Ceres	7.38	1.48	1.88
Early Red Fife	0.71	1.11	1.16
Type IC	6.52	5.66	6.10
Reliance	0.02	—	0.10
Kota	1.46	0.73	1.45
Pioneer	0.04	0.37	0.18
Coronation	—	—	0.02
Kitchener	0.07	0.12	0.04
Huron	0.11	0.12	0.16
Preston	0.40	0.12	0.14
Stanley	0.42	0.37	0.37
Parkers Sel.	1.81	4.05	1.06
Fishers	—	—	0.04
Prelude	0.06	—	0.02
Quality	—	—	0.04
Miscellaneous	1.83	1.62	2.12
Ladoga	0.57	0.37	0.18
White Russian	0 11	0.25	0.04
Early Russian	0.11	—	—
Club or Red Club	0.04	0.12	—
6 Row Barley	0.07	—	0.08
2 Row Barley	—	—	0.04
Number of cargoes	25	4	25

SOIL FERTILITY STUDIES

I. MANURE, FERTILIZERS AND LIME FOR FIELD CROPS AT STE. ANNE DE LA POCATIÈRE, P.Q.[1]

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It is generally known that on most Canadian soil types the majority of field and horticultural crops respond in a very marked degree to the application of a phosphatic fertilizer. In many instances available phosphoric acid has been found to be the chief limiting factor of crop production in so far as the supply of plant food constituents is concerned. The following report of results obtained in an experiment dealing with the use of manure, fertilizers and lime at the Dominion Experimental Station at Ste. Anne de la Pocatière, P.Q., furnishes additional support to the above mentioned conclusion. The chief object of the experiment was to determine a suitable combination of manure and fertilizer for the production of field crops.

The soil of the area is an upland podsol gravelly loam containing a considerable amount of shale particles. Analysis of a composite sample from the check plots in 1946 showed that 36.0 per cent failed to pass a 2 mm. sieve. The pH was 5.4, loss on ignition 6.07 per cent, nitrogen 0.22 per cent, P_2O_5 readily soluble in acid potassium sulphate (pH, 2) 23 p.p.m., and exchangeable CaO, MgO and K_2O 0.185, 0.011 and 0.026 per cent, respectively.

The experiment was commenced in 1932 and the treatments were applied for the turnip crop in a four-year rotation of turnips, oats, clover and timothy on 1/50 acre plots in duplicate. On adjacent experimental areas the same treatments were commenced in 1933, '34 and '35. Consequently the yield data herein reported represent 14 crops of turnips, 13 of oats, 12 of clover and 11 of timothy hay. The treatments and crop yields obtained during the 14-year period 1932-1945 are tabulated in Table 1.

DISCUSSION OF RESULTS

Yields

Turnips.—The response of the turnip crop to the application of a phosphatic fertilizer was outstanding. This result is demonstrated by comparisons as follows:

Plot No.	Treatment	Yield of turnips (tons per acre)
14	Control	4.02
5	Superphosphate	13.90
4	Basic slag	11.54
12	N + K	5.14
10	N + P + K	14.12

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TABLE 1.—AVERAGE YIELDS 1932-1945

Plot No.	Treatments per acre (applied once in the rotation for the turnip crop)		Yields per acre			
			Turnips average of 14 years	Oats average of 13 years	Clover average of 12 years	Timothy average of 11 years
			(tons)	(bush.)	(tons)	(tons)
1	Ground limestone	2 tons	5.18	30.4	1.29	1.05
2	Rock phosphate	350 lb.	9.10	30.0	1.49	1.22
3	Hydrated lime	2240 lb.	5.53	36.3	1.51	1.22
4	Basic slag	750 lb.	11.54	36.0	2.13	1.77
5	Superphosphate	750 lb.	13.90	36 0	1.92	1.72
6	Manure	20 tons	17.72	39.1	2.32	1.87
7	Ground limestone Manure	2 tons 20 tons	19.06	46.5	2.68	2.15
8	Ground limestone Superphosphate	1 ton 500 lb.	13.06	35.8	1.96	1.64
9	Manure Nitrate of soda Sulphate of ammonia Superphosphate Muriate of potash	10 tons 100 lb. 75 lb. 400 lb. 100 lb.	17.63	39.5	2.37	1.81
10	Nitrate of soda Sulphate of ammonia Superphosphate Muriate of potash	100 lb. 75 lb. 400 lb. 100 lb.	14 12	30.5	1.76	1.33
11	N + P as in 10		13.12	34 8	1.85	1.39
12	N + K as in 10		5 14	28.5	0.95	0.85
13	P + K as in 10		12.14	34.5	1.46	1.21
14	Check plot		4 02	25.5	0.93	0.84
	Necessary difference for significance ($P = 0.01$)		2.57	3 8	0.27	0.26

When the phosphoric acid component of the complete fertilizer was omitted as in plot 12, the yield of turnips was very low and not significantly greater than that of the control plot 14.

When nitrogen and potash were omitted from the complete fertilizer as in plots 13 and 11, respectively, shown in Table 1, the yields declined slightly but the decreases were not significant. All three manure treatments whether alone, in conjunction with ground limestone or supplemented by a complete fertilizer gave significantly larger yields than the complete fertilizer. The application of lime alone as in plots 1 and 3 did not significantly increase the yield but it is noteworthy that although the addition of ground limestone to the manure treatment did not give a significant increase over the manure alone dressing, it resulted in the largest yield. The above results indicate that the application of a phosphatic fertilizer for the production of turnips on the soil under study is all-important.

To illustrate the trend of the yields of turnips over the experimental period under review the yields of certain plots are plotted in Figure 1.

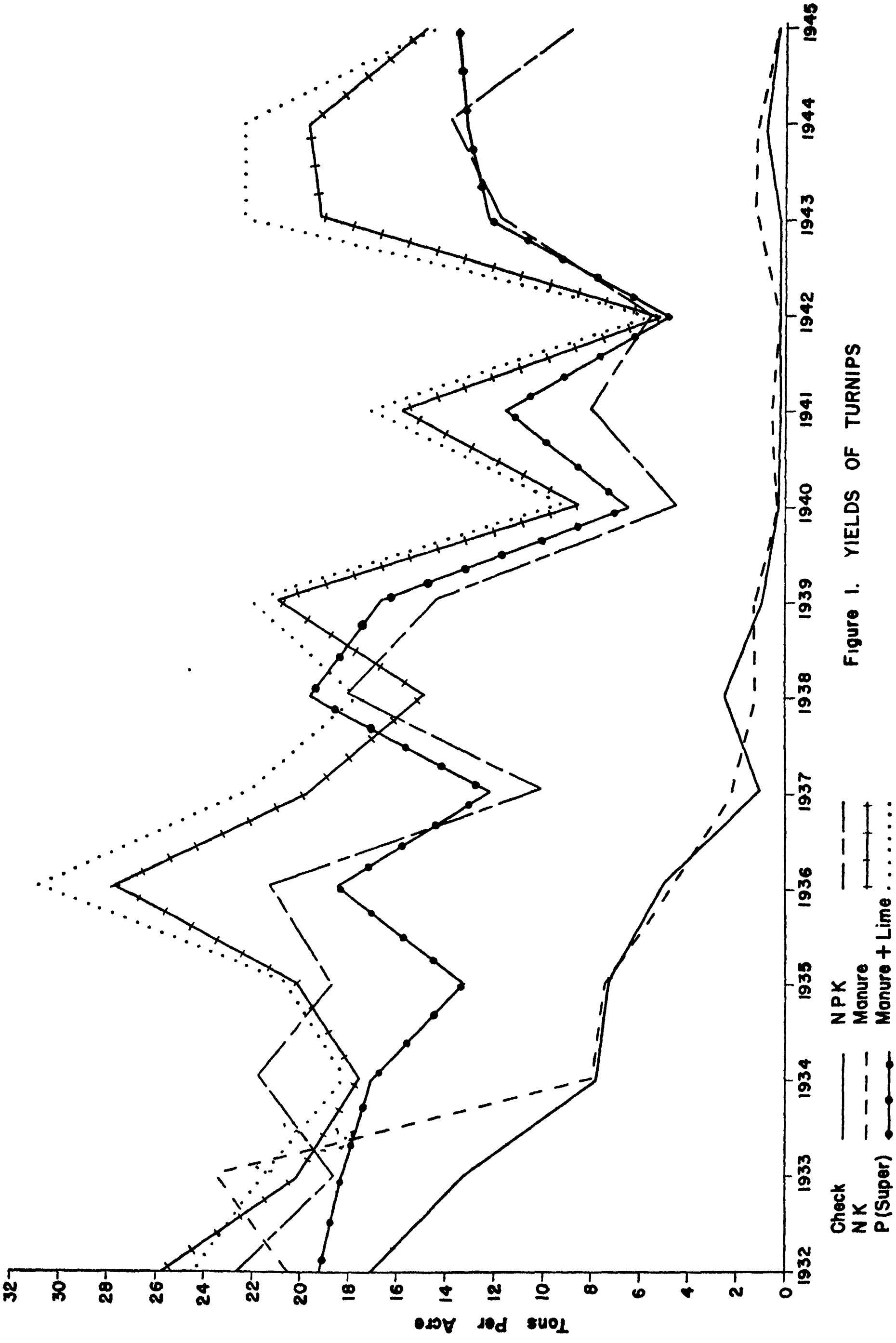

Figure 1. YIELDS OF TURNIPS

It will be noted that the yields from all treatments at the beginning of the experiment were quite satisfactory. However, on the plots where no phosphoric acid was applied, viz. the control and N K plots, the yields rapidly declined and remained at a very low level. On the plots which received phosphoric acid in the P, NPK, Manure and Manure + Lime treatments the yields varied considerably apparently due to seasonal conditions.

For instance, average yields prevailed on the fertilized plots from 1932 to 1935 and a study of precipitation records for the growing season May to September, as shown in Table 2, reveals a normal or slightly lower than normal rainfall for the whole five months. The highest yields for the duration of the experiment were obtained in 1936 in which season there was a high rainfall of 5.48 inches in May followed by normal precipitation for the remainder of the season. In 1940 and 1942 when turnip yields were lowest the precipitation was high in June, 6.54 inches and 7.09 inches, respectively and low in July, 2.10 inches in 1940 and 2.18 inches in 1942. In 1942 when all of the yields were low and fertilizer and manure were equally ineffective the dry July was followed by a drier August, 1.47 inches being recorded. The low yields in 1937 were apparently due to the very wet season when a rainfall of 29.37 inches was recorded during the five months and a record monthly rain of 9.21 inches was received in August. On the whole, however, the inclusion of manure in the soil management program has proved best for the growth of turnips on this type of soil.

TABLE 2.—PRECIPITATION, MAY TO SEPTEMBER, STE. ANNE DE LA POCATIÈRE, P.Q.

	May	June	July	August	September	Total
1932	1.30	3.45	4.46	5.83	5.03	20.07
1933	3.29	3.40	2.00	3.45	1.95	14.09
1934	1.85	4.87	2.94	3.77	2.19	15.62
1935	1.17	4 80	5.07	3.56	3.12	17.72
1936	5.48	3.24	3.39	2.46	3.33	17.90
1937	5.13	3.06	5.50	9.21	6.83	29.73
1938	2.47	3.19	6.01	6.09	6.59	24.35
1939	2.94	3.72	3.30	3 91	4.57	18.34
1940	3.46	6.54	2.10	3.21	3.07	18.38
1941	1.43	5.91	3.15	4.32	7.38	22.19
1942	1.99	7.09	2.18	1.47	3.85	16.58
1943	2.41	3.65	2.92	5.20	1.72	15.90
1944	1.18	2.65	5.53	3.55	3.91	16.82
1945	4.14	2.60	5.63	3.15	6.48	22.00

Oats.—All treatments, except that on plot 12 where the phosphoric acid of the complete fertilizer was omitted, gave significantly larger yields of oats than the control plot. As in the case of the turnips, the application of manure produced the highest yields, the increases over the control varying from 53 per cent, where the manure was used alone, to 82 per cent where the manure was supplemented with ground limestone. While there are certain inconsistencies in the response of the oat crop to the plant food constituents applied, the residual effect of the lime was quite marked on plot 7 where ground limestone was used with manure and on plot 3 where hydrated lime was used alone. The somewhat low yields on the NPK

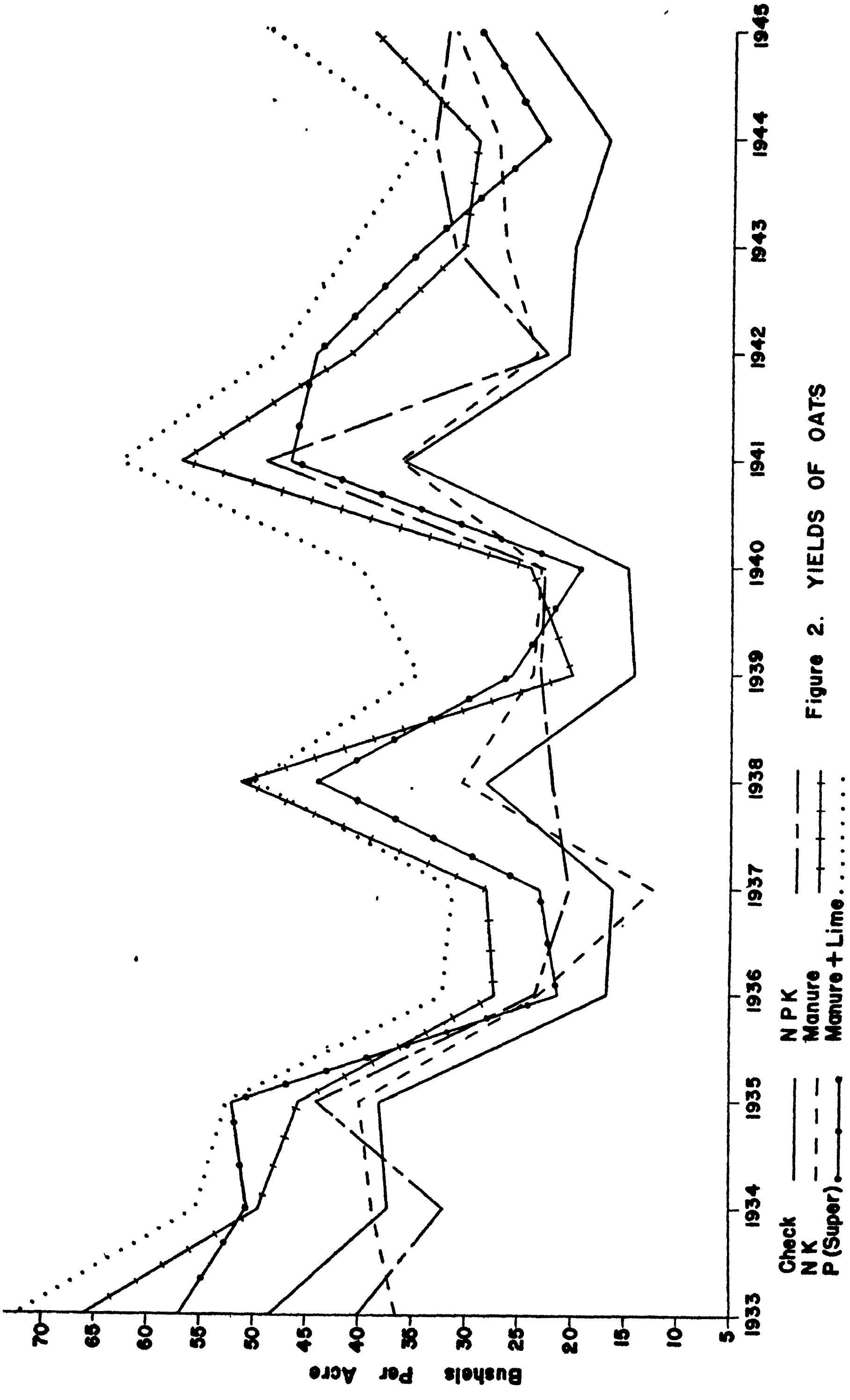

Figure 2. YIELDS OF OATS

plot are difficult to understand particularly when the NP and PK treatments gave significantly higher yields. The yields of oats from certain treatments for each year are plotted in Figure 2.

As in the case of the hoed crop the yields varied greatly with the season. The yields from the NPK treatment were consistently low from 1936 to 1940 and in 1942. This would account for the low average yields of oats from this treatment during the total experimental period. The other treatments showed a fairly uniform trend according to the season with the manured and superphosphate plots producing the best yields.

Precipitation records (Table 2), indicate the reasons for some of the season to season variations in oat yields as was the case with turnips. The yields were reasonably normal from 1933 to 1935 and so was the rainfall. The low yields in 1936 were affected by the wet May, with 5.48 inches of rain which interfered with seeding operations and early growth. The 1937 season was wet throughout and the yields of all crops in the rotation were low. High yields were obtained in 1938 although the seasonal rainfall was abnormally high. May, however, was reasonably dry with 2.47 inches of rain which allowed for early seeding and this was followed by a normal precipitation of 3.19 in June. The remaining three months all had a rainfall over 6 inches. No explanation is available for the low yield in 1939 which had normal rainfall throughout the season. In 1940 the low yield may have resulted from 6 54 inches of rain in June. In 1941 as in 1938 with high yields the month of May was dry, 1.43 inches of rain followed by ample rain for the remainder of the season.

Clover Hay.—The residual effect of the majority of the treatments applied two years previously was quite marked on the clover hay crop. As in the case of turnips and oats the largest yields were obtained where manure was applied. The combination of manure and ground limestone gave yields significantly higher than any of the other treatments. The importance of the application of lime and available phosphoric acid for the growth of clover hay is evident by the yields obtained on plot 4 where basic slag was used and on plot 8 where ground limestone and superphosphate were applied. Omission of the phosphoric acid component of the complete fertilizer on plot 12 reduced the yield to the same order as that of the control plot. The yields of clover hay, from selected treatments, obtained during the period 1934-45 are plotted in Figure 3.

As was found with the turnip crop, when phosphoric acid was omitted from the fertilizer treatment, viz. check and NK, the yields of clover hay were of the same order of magnitude and markedly lower than those where this element of plant food was applied in manure, a complete fertilizer or superphosphate.

In 1938 the season was especially favourable for the production of hay since there was ample rain. It was probably also favoured by the 1937 season which, although too wet for good crop growth generally, was ideal for establishing a stand of new seeding. The high yield in 1942 may be attributed to a high June rainfall of 7.09 inches followed by comparatively dry weather which provided for good harvesting conditions but was not dry enough to retard growth. The low yield in 1937 followed the same pattern as that of the other crops. Apparently the season was too wet even for the growth of hay.

Timothy Hay.—The residual effect of the treatments on the timothy hay crop was similar to that on the clover hay. The application of manure gave the largest yields and phosphoric acid and lime were the most effective of the plant food constituents applied. While the omission of the nitrogen and potash from the complete fertilizer (plots 13 and 11) did not significantly alter the yields as obtained on the NPK plots, leaving out the phosphoric acid component (plot 12) reduced the yield to the same order as the control plot.

The above results indicate that on this type of soil for the production of field crops the reduction of soil acidity with either ground limestone or slaked lime and the application of a dressing of manure will maintain soil fertility. Where the supply of manure is limited good results may be expected from the use of a small dressing of manure supplemented with superphosphate.

EFFECT ON SOIL COMPOSITION

Variations in the composition of the soil at the end of the 14-year period were quite pronounced. In 1946 samples of the surface soil from certain of the plots were analysed and the results are presented in Table 3.

TABLE 3.—ANALYSIS OF SOIL SAMPLES

Plot No.	Treatment per acre	pH	Moisture	Loss on ignition	Nitrogen	Readily soluble P_2O_5*	Exchangeable CaO**	Exchangeable K_2O**
			%	%	%	p.p.m.	%	%
14	Check	5.4	1.9	6.07	0.22	23	0.19	0.026
5	Superphosphate, 750 lb.	5.4	2.3	7.85	0.27	91	0.20	0.014
6	Manure, 20 tons	5.6	2.4	7.88	0.28	93	0.21	0.031
7	Manure, 20 tons Ground limestone, 2 tons	7.1	2.0	8.24	0.29	70	0.46	0.037
12	Nitrate of soda, 100 lb. Sulphate of ammonia 75 lb. Muriate of potash, 100 lb.	5.7	1.9	7.18	0.24	29	0.19	0.028

* Extracted with $KHSO_4$ at pH 2.0.
** Extracted with neutral N NH_4OAc.

The above analyses show that where ground limestone was applied every four years as in plot 7 the soil reaction was about neutral whereas on the other plots it was strongly acid. The readily soluble phosphoric acid of the soil on the plots which received this element in the fertilizer treatment was 3 to 4 times greater than that of the check and N + K plots. This might be due to the fact that the soil was originally low in phosphoric acid or that the continuous removal of this element by cropping without any return by fertilizer or manure has resulted in a very low level of this constituent. The latter explanation is supported by the trend of the yields shown in Figure 1. The low exchangeable potassium content of plot 5 which received only superphosphate might be due to depletion of that element by the increased crop yields from the phosphatic fertilizer. The

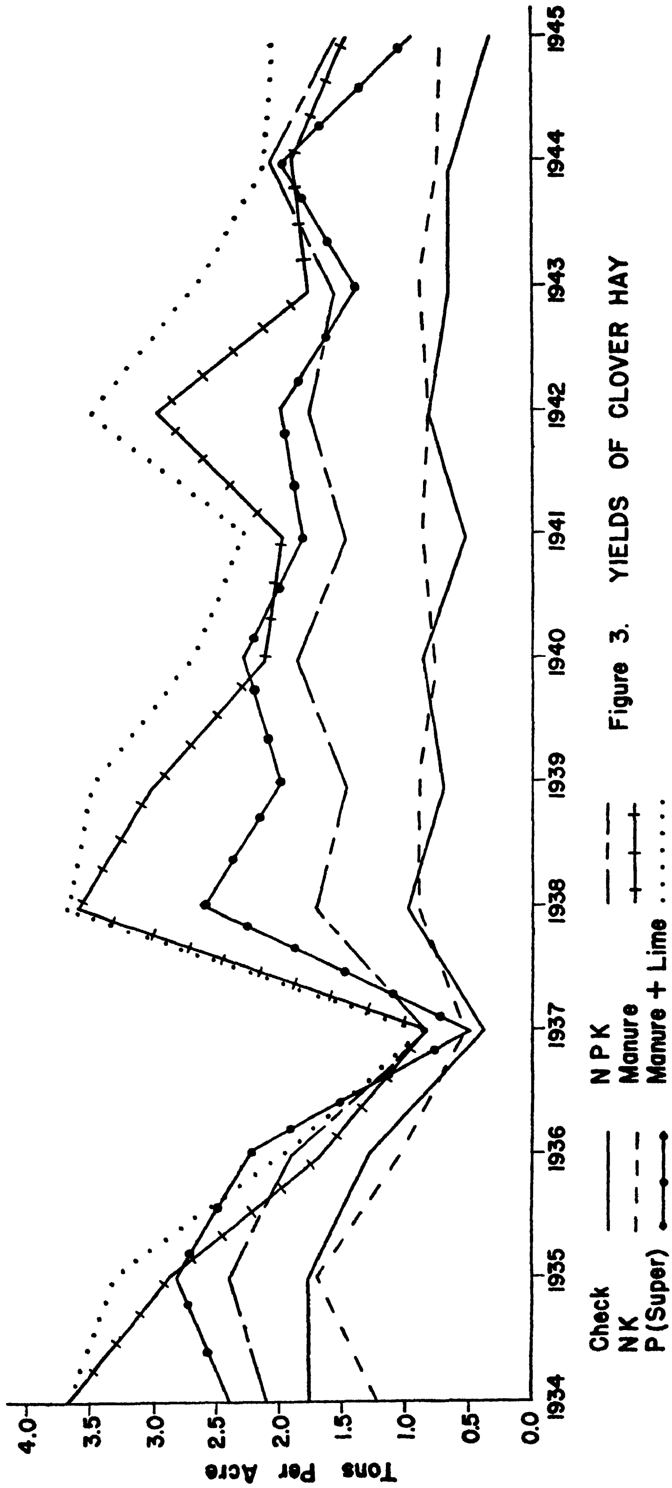

Figure 3. YIELDS OF CLOVER HAY

nitrogen and organic matter (by loss on ignition) contents of the soil on plots 5, 6 and 7 are appreciably higher than those of the check and N + K plots. This may be a reflection of the effect of the manure applied and the increased hay crop residue from the larger yields obtained on the former plots.

SUMMARY

The effect of applications of nitrogen, potash, manure, three sources of phosphoric acid and two of lime were studied at the Dominion Experimental Station, Ste. Anne de la Pocatière, over the period 1932 to 1945. The above materials were applied to the hoed crop in a four-year rotation of turnips, oats, clover hay and timothy hay.

Nitrogen and potash applications had little effect on the yield of all crops of the rotation.

Phosphatic fertilizers applied to the hoed crop greatly increased the yields of turnips, clover hay and timothy hay and in some years benefited the oats crop. Superphosphate and basic slag applied alone proved about equally effective and both were distinctly superior to rock phosphate.

Where phosphoric acid was omitted from the fertilizer treatment the yields rapidly declined and remained at a very low level.

Ground limestone and hydrated lime slightly improved the yield of hay crops.

The application of manure gave the highest yields of all crops over the experimental period. It would appear that the best treatment for the growth of field crops on the soil under experimentation was a combination of manure and superphosphate.

The amount and distribution of the precipitation during the growing period greatly affected crop yields and fertilizer response.

ACKNOWLEDGMENT

Acknowledgment is made to F. J. Sowden of the Division of Chemistry, Science Service, Department of Agriculture, for assistance in making the statistical examination of the field data.

PHOSPHORUS STUDIES

I. EFFECTS OF FLOODING ON SOIL PHOSPHORUS[1]

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This paper is the first of a series of three, the primary objective of which will be consideration of the interrelation of the phosphatic, the sesquioxidic and the organic matter fractions of soils.

The present investigation was suggested by a problem in plant nutrition occurring in the sugar-producing area of the Lowlands of British Guiana. The soils of this area are heavy clays which are strongly acid, low in total phosphorus content and very low in easily-soluble phosphorus. The juice from sugar-cane produced on these soils is low in phosphorus. There is reason to believe that the quality of the juice would be improved and the yield of cane increased if an improvement in the phosphorus nutrition of the crop could be effected. Applications of rock phosphate and of superphosphate to these soils, however, have failed to produce significant responses either in yield of cane or in quality of juice.

For the past fifty years it has been customary to flood the cane-fields of the British Guiana Lowlands with water to a depth of about six inches and to maintain this flooded condition for at least six months, often longer, before replanting to cane. The cane plantations being on dyked land, flooding with river water is an easy matter. Molasses sometimes is added to the flood water. This practice, referred to locally as "flood-fallowing," is considered to have produced beneficial results from the standpoint of crop production.

In a recent survey of these soils by Hardy and Rodrigues (6) it was found that the easily-soluble phosphorus content (Truog method) of these soils sharply increased at depths of twenty to forty inches, that is, in the vicinity of the upper surface of the water-table. These authors suggested downward movement of phosphorus had occurred, particularly in the flood-fallowed soils.

In summary, the picture presented was that of soils decidedly low in total phosphorus and very low in acid-soluble phosphorus, periodically subjected to the anaerobic conditions of prolonged flooding followed by periods of considerable desiccation during the growth of the new cane, and containing an accumulation of acid-soluble phosphorus at the water-table level.

Consideration of this picture suggested that the flooding practice might be related, not only to the distribution of easily-soluble phosphorus within the profile (as already suggested by Hardy and Rodrigues), but also to the solubility and availability of the phosphorus in the part of the soil lying above the permanent but fluctuating water-table. It was decided to subject this hypothesis to experimental test. It was at that time (1946-7) quite impracticable, however, to obtain from British Guiana samples of

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soil in quantity sufficient for the experiments proposed. Hence it was decided to investigate the effects of flooding on the phosphorus status of a Canadian soil. In view of the fact that large areas of Eastern Canadian soils of heavy texture are imperfectly to poorly drained and are, therefore, subject to periodic water-logging, it was thought that the proposed investigation might yield results of interest to agriculturists both in this region and in British Guiana.

The Ste. Rosalie soil was selected for experimentation, primarily because it was a readily available, imperfectly drained soil of rather heavy texture, but also because it occupies a large area in the St. Lawrence Lowland Plain and is a soil of considerable agricultural importance. The Ste. Rosalie is an intrazonal soil derived from marine clay and having a weakly developed profile. The typical profile of this soil under cultivation may be described* as follows:

The 0-7-inch ploughed layer is a dark gray clay to clay loam, granular in structure, slightly plastic, and ranges in pH from 5.5 to 6.5. Immediately below the ploughed layer and extending to a depth of about 12 inches, the soil is a brownish-gray to rusty-brown clay with mottling of a rusty colour and with a few light-gray spots. The soil in this second layer has a weakly-developed granular structure, is plastic and ranges in pH from 5.7 to 6.5. The parent material at 24 inches and below is a gray clay with fine to medium blocky structure, very plastic, and ranging in pH from 6.7 to 7.3.

The large sample of Ste. Rosalie soil used in the present study was taken from the upper 12 inches of a cultivated field near St. Polycarpe, Soulanges Co., P.Q. The sample was air-dried, well mixed, and representative portions were sieved on a 2 mm. sieve. The soil passing this sieve was used for analysis and experimentation. The pH of the sample, 6.9, was somewhat higher than usual for the upper horizon of this soil. Physical analysis by the international pipette method showed that the sample contained 47.5 per cent total sand, 12.3 per cent silt and 31.2 per cent clay (0.002 mm.). The organic matter content (Walkley (12) method) was 2.7 per cent and the loss on ignition was 4.9 per cent.

FLOODING TECHNIQUE

Samples of 800 gm. each were placed in conical-form glass percolators over small plugs of absorbent cotton which acted as filters for the percolates. These samples then were flooded with 800 ml. of distilled water or 800 ml. of one per cent glucose solution. This volume of flooding liquid gave a depth of about 3 inches over the soil. The depth of soil in the percolators was approximately 6 inches. Two conditions of flooding were employed, Free Drainage and Stagnant. In the former, free downward movement of the flooding liquid was permitted, and, when the liquid-level nearly reached the soil surface, additional liquid was added to restore the supernatant depth to 3 inches. Outgo of the flooding liquid was slow, the total volume added in a period of 30 days being about 3 liters. In the Stagnant systems the tubules of the percolators were closed by rubber tubing fitted with

* Private Communication, P. Lajoie, Soil Specialist, Experimental Farm Service, Dominion Department of Agriculture, Macdonald College, P.Q.

clamps. Flooding liquid was added only as required to compensate for evaporation losses. Both systems were operated at laboratory temperatures.

METHODS OF ANALYSIS

Unless otherwise specified, all determinations of phosphorus were made by the Truog-Meyer procedure (10) using an Evelyn photo-electric colorimeter with a 660 mu filter. The results are expressed in terms of the element and on the air-dry soil basis. For the estimation of the total phosphorus content of the soil 0.5 gm. samples (100-mesh) were fused with sodium carbonate and the melt extracted with hot water. The solution was acidified and carbon dioxide expelled before colour development.

Easily-soluble phosphorus was extracted using the solution, the soil-solution ratio, and the time of shaking recommended by Truog (11), but employing 1.0-gm. samples of air-dry soil or equivalent weights of wet soil. The inorganic phosphorus content of the extract was determined colorimetically as indicated above, and the total phosphorus content similarly after having evaporated an aliquot of the extract to dryness in presence of a suitable amount of normal magnesium nitrate solution and ignited the residue. The residue was dissolved in 25 ml. of 0.5 N sulphuric acid solution and filtered before colour development. The difference between the results of these two determinations was assumed to represent easily-soluble, organically-combined phosphorus.

In the fractionation of soil phosphorus the method of Dean (2) was employed. The total NaOH-soluble phosphorus was determined after treatment of an aliquot of the solution with magnesium nitrate as described above. In the estimation of inorganic NaOH-soluble phosphorus an aliquot of the sodium hydroxide extract corresponding to 0.75 gm. soil was treated with one gram of charcoal (Darco G. 60), filtered, and the phosphorus content of the filtrate determined in the usual way. The difference between the total NaOH-soluble and the inorganic NaOH-soluble phosphcrus determined in this way was assumed to represent organically-combined phosphorus soluble in NaOH-solution.

Anion exchange capacity was estimated by the method of Rubins and Dean (9). Colour due to organic matter was removed from the NH_4F displacing solution by treatment with charcoal (Darco G. 60), after which the phosphorus content of the filtrate was determined by the method of Gerritz (5) as modified by Kurtz (8) to eliminate interference by fluoride ion. Light transmittance was measured as usual.

RESULTS AND DISCUSSION

The duration of the first flooding experiment was 30 days. At the end of this time the liquids were withdrawn from the soils and the latter sampled for analysis at the 0 to 2 inch, 2 inch to 4 inch and 4 inch to 6 inch levels. The analytical samples consisted of weights of wet soil equivalent to one gram of air-dry soil. The easily-soluble inorganic and organic phosphorus contents of extracts from these samples were determined. The results obtained for the Free Drainage System, together with the pH values found for the moist flooded soils, are presented in Table 1. Similar data for the leachates obtained during the flooding period and for the original soil are included.

Examining first the changes in pH induced by flooding, it is seen from Table 1 that flooding with water only has tended to increase the pH slightly, whereas flooding with glucose solution has produced a remarkable decrease in this characteristic. Relative to the latter, it was noted that active anaerobic fermentation, accompanied by a marked "butyric" odour and considerable evolution of gas, occurred in the soil-glucose solution system, especially during the first week of treatment. Doubtless the acids produced in this fermentation are responsible for the change in pH of this system. A very slight evolution of gas was noted in the case of the soil-water system.

It will be noted also that the data for easily-soluble inorganic phosphorus shown in Table 1 suggest that a downward movement of this fraction has occurred, especially in the soil-glucose solution system. This indication is supported by the fact that small amounts of inorganic phos-

TABLE 1.—EFFECTS OF FLOODING, UNDER CONDITIONS OF FREE DRAINAGE, ON THE SOIL pH AND ON THE AMOUNT, NATURE AND DISTRIBUTION OF ACID-SOLUBLE PHOSPHORUS EXTRACTED BY THE TRUOG REAGENT

Sampling depth (inches)	Flooded with water for 30 days			Flooded with 1 0 per cent glucose solution for 30 days		
	pH	Inorganic phosphorus p.p.m.	Organic phosphorus p.p.m.	pH	Inorganic phosphorus p.p.m.	Organic phosphorus p.p.m.
0 – 2	7 09	152	30	4 10	140	30
2 – 4	7 11	155	43	4 35	165	48
4 – 6	7 26	170	30	4 48	187	37
In leachates	6 80	0 600	—	4 40	0 640	—
Before flooding	6 92	160	8	—	—	—

TABLE 2.—EFFECTS OF FLOODING, UNDER STAGNANT CONDITIONS, ON THE SOIL pH AND ON THE AMOUNT, NATURE AND DISTRIBUTION OF ACID-SOLUBLE PHOSPHORUS EXTRACTED BY THE TRUOG REAGENT

Sampling depth (inches)	Flooded with water for 30 days			Flooded with one per cent glucose solution for 30 days		
	pH	Inorganic phosphorus p.p.m.	Organic phosphorus p.p.m.	pH	Inorganic phosphorus p.p.m.	Organic phosphorus p.p.m.
0 – 2	6 88	161	41	5 26	149	53
2 – 4	6 94	159	44	5.94	151	50
4 – 6	7.03	166	34	6.19	162	53
	Flooded with water for 60 days			Soil before flooding		
0 – 2	7.06	143	51	6.92	160	8
2 – 4	7.14	148	55	—	—	—
4 – 6	7.24	154	59	—	—	—
	Flooded with water for 90 days					
0 – 2	6.96	147	64	—	—	—
2 – 4	7.01	149	51	—	—	—
4 – 6	7.24	165	49	—	—	—

phate were found in the leachates. The data also indicate a definite accumulation of easily-soluble organic phosphorus under the conditions of the experiment, the amounts found being closely the same regardless of the nature of the flooding liquid used.

In Table 2 the corresponding results for the Stagnant systems are reported. Under this condition separate soil samples were flooded with water only for periods of 30, 60 and 90 days, respectively, with glucose solution for 30 days only. The same tendencies in respect of pH change are noted as in the case of the Free Drainage systems but in lesser degree. In the Stagnant systems also there is but little evidence of movement of easily-soluble phosphorus. The accumulation of easily-soluble organic phosphorus, on the other hand, is as great or somewhat greater than in the Free Drainage systems.

After withdrawal of the flooding liquids and taking samples for analysis from the two types of systems just considered, the wet soils were allowed to air-dry, were re-crushed to pass the 2 mm. sieve, and then re-analysed for easily-soluble phosphorus content. The results obtained are recorded in Table 3.

TABLE 3.—PH VALUES, AND THE AMOUNT AND NATURE OF ACID-SOLUBLE PHOSPHORUS EXTRACTED BY THE TRUOG REAGENT FROM FLOODED SOILS AFTER AIR-DRYING, WITH THE PERCENTAGE CHANGE IN THE INORGANIC PHOSPHORUS FRACTION INDUCED BY FLOODING AND AIR-DRYING

Conditions of flooding	Acid-soluble phosphorus		Per cent change in acid-soluble inorganic	pH air-dried soils
	Inorganic p.p.m.	Organic p.p.m.		
Free Drainage System—				
30 days flooding with water	156	26	2.6	7.05
30 days flooding with 1.0 per cent glucose solution	42	21	73 8	4.20
Stagnant System—				
30 days flooding with water	141	29	11 9	7.20
60 days flooding with water	118	32	26.3	7.34
90 days flooding with water	114	37	28 8	7.25
30 days flooding with 1 0 per cent glucose solution	67	23	58.1	5.48
Not flooded—				
Original soil	160	8	—	6.92

Examination of Table 3 shows that, after air-drying, the amount of easily-soluble organic phosphorus extractable is in every instance (compare Tables 1 and 2) less than was obtainable from the still moist soils after flooding, although still about three times as great as was extractable from the original air-dry soil. The decrease in this fraction on air-drying may be due to breakdown of organic to inorganic phosphate. If such a breakdown has occurred, however, it has not resulted in a corresponding increase in the easily-soluble inorganic fraction, for, in every instance except for the 30-day-water-Free Drainage system, the values for inorganic phosphorus shown in Table 3 are definitely less than those for the original air-dry soil

TABLE 4.—EFFECT OF FLOODING ON THE ANION EXCHANGE CAPACITY OF THE STE. ROSALIE SOIL

Conditions of flooding	Anion exchange capacity millimols phosphorus/100 gm. soil
Free Drainage System—	
30 days flooding with water	13.8
30 days flooding with 1.0 per cent glucose solution	15.2
Stagnant System—	
60 days flooding with water	15.2
90 days flooding with water	15.2
Unflooded—	
Original soil	12.1

and less than those for the wet soils at the end of the flooding period (as shown in Tables 1 and 2). The percentage decreases from the amount of easily-soluble inorganic phosphorus found in the original soil, as shown in the third column of Table 3, are very considerable in the case of both the soil-glucose solution systems. They also are of an important order of magnitude for the longer periods of flooding with water under stagnant conditions.

It seems clear from the results reported in Table 3 that flooding of soils for extended periods, especially in presence of an abundant supply of easily-decomposable organic matter, and particularly when the flooding is followed by desiccation, may have a very undesirable effect upon the available phosphorus of the soil as measured by extraction with dilute solution of mineral acids.

In relation to these results it is pertinent to note that Allison and Scarseth (1) have proposed a biological method for removing oxides of iron from soils; that Ford (4) has demonstrated that hydrated oxides of ferric iron fix greater amounts of phosphate per unit weight of iron than does the anhydrous form of ferric oxide; and also that Follett-Smith and Robinson (3) working with the cane soils of British Guiana, and, more recently, Hester and Skelton (7) studying Ontario soils, have reported an increased soluble iron content in flooded soils. Further, Allison and Scarseth (1) observed that if soil previously incubated with glucose solution was washed with a 0.5 N solution of sodium chloride, the capacity of the residual soil for phosphorus fixation was less than that of the original soil. In view of these observations, it is thought that the results obtained in the present investigation reasonably may be explained as due to biological reduction of iron during the flooding phase, followed by re-oxidation during the desiccation phase, the net result of these phenomena being an increase in the phosphorus-fixing capacity of the sesquioxidic fraction of the Ste. Rosalie soil. Experimental evidence in support of this hypothesis was obtained in the following manner: A sample of soil flooded with glucose solution for 30 days was washed with 0.5 N NaCl solution before air-drying while a duplicate sample was air-dried without washing. On

estimation of the easily-soluble inorganic phosphorus extractable from the two samples it was found that the one which has been washed yielded 107 p.p.m., the one not washed only 42 p.p.m. of this phosphorus fraction. Further and more direct evidence that flooding with subsequent air-drying produced an increase in the reactivity of the sesquioxide fraction of the Ste. Rosalie soil was obtained from estimation of the anion exchange capacities of flooded samples and of the original air-dry soil. The results of these determinations are reported in Table 4.

Both the invariable occurrence of an increase in exchange capacity of the flooded and air-dried samples, and the magnitude of the increases found, indicate that significant changes in this soil property resulted from the treatments applied. It seems noteworthy that 60 days flooding with water only was capable of producing as large an effect as did 30 days flooding with glucose solution.

Application of the Dean fractionation procedure to flooded and air-dried samples supplied still further evidence of change in the reactivity of the sesquioxidic fraction. Thus, as will be seen from the data presented in Table 5, marked increases in the amounts of phosphorus present in the inorganic alkali-soluble fraction, generally considered to consist mainly of phosphates of iron and of aluminium, were produced by the experimental treatment.

TABLE 5.—PERCENTAGE DEVIATIONS FROM THE VALUES FOUND FOR THE DEAN FRACTIONS BY ANALYSIS OF THE ORIGINAL AIR-DRIED SOIL

Treatment	Inorganic alkali-soluble	Organic alkali-soluble	Inorganic acid soluble	Inert
Free Drainage—				
Flooded 30 days with 1 0 per cent glucose solution	21 9	20 2	−7 1	−25 1
Stagnant—				
Flooded 30 days with 1 0 per cent glucose solution	21 9	10 6	−7 1	−20 8
Flooded with water 30 days	11 3	7 7	−2 1	−12 6
Flooded with water 60 days	17 5	11 5	−3 1	−17 7
Flooded with water 90 days	25 0	5 8	−7 1	−19 9

Examination of Table 5 shows that the distribution changes resulting from treatment are consistent in sign throughout, that, in general, the greatest changes followed treatment with glucose solution, and that the extent of the changes produced in the water-flooded soils is in proportion to the duration of the flooding period. The magnitude of the decrease in the so-called inert phosphorus fraction suggests that, in so far as the Ste. Rosalie soil is concerned, this fraction contained substances reactive under the conditions of the experiment. It may be noted also that the absolute increases in the amounts of organic alkali-soluble phosphorus were less than the increases in easily-soluble organic phosphorus reported earlier. Possibly some of the latter fraction was decomposed to inorganic phosphate during the rather drastic alkali-extraction treatment of the Dean procedure.

Since the results indicated that an undesirable effect upon the "available" phosphorus content of the soil was produced by flooding followed by drying, it was of interest to determine whether or not this effect might be prevented. In this connection, current theory respecting the mechanism of phosphorus fixation in soils suggested that the application of lime to the moist soil after flooding might prevent the decrease in easily-soluble phosphorus. It was found, however, that the addition of saturated $Ca(OH)_2$ solution, at rates equivalent to from 2 to 7 tons of calcium carbonate per 2 million pounds of air-dry soil, to the moist soil from the 30-day glucose solution-Free Drainage system before air-drying failed to produce the desired result. This treatment did have some effect, the amount of extractable easily-soluble inorganic phosphorus being raised, on the average, from 42 to 57 p.p.m. The latter value, however, still represents a decrease of more than 60 per cent from the amount found in the original air-dry soil. This finding suggests that liming an acid soil may fail to prevent fixation of soluble phosphate by the sesquioxide fraction. Further observations relative to this point will be made in the second paper of this series.

The experimental results already recorded indicate that the desiccation phase is more important than the flooding phase in so far as effect on the extractability of easily-soluble inorganic phosphorus is concerned. It was of interest, therefore, to determine whether or not a decrease in this fraction of the soil phosphorus would occur in the moist soil after the excess of the flooding liquid had been withdrawn. In this connection, experiment showed that, when stored in a desiccator over a free water surface, the easily-soluble inorganic phosphorus content of samples of moist soil taken from the 30-day glucose solution-Free Drainage system remained constant (within the limits of experimental error) for a period of eight weeks. This result indicates that restriction of the free oxygen supply and prevention of desiccation will serve to prevent the decrease in extractable inorganic phosphorus found to result from air-drying. This finding may prove to be of practical value in respect of the phosphorus nutrition of sugar cane in the British Guiana Lowlands, where the height of the water-table within the soil profile easily may be regulated. This result also raises the question of the effect of improvement of drainage on the availability of phosphorus in the profiles of presently imperfectly-drained soils in Eastern Canada. Further study of the effects of different levels of oxygen supply and of varying degrees of desiccation is desirable.

As has been seen, on drying subsequent to flooding a part of the soluble phosphorus present in the Ste. Rosalie soil was converted to less readily extractable forms. It seemed probable soluble phosphate added to the soil also would suffer a similar change. An experimental test of this possibility was conducted using both wet and air-dried samples of flooded soil and a sample of the unflooded air-dry soil. Samples equivalent to one gram air-dry weight were taken; to each of these were added 5 ml. of KH_2PO_4 solution containing phosphorus equivalent to 250 p.p.m. of air-dry

soil. The mixtures were well stirred, placed in desiccators at zero humidity (over concentrated sulphuric acid) and at 100 per cent relative humidity (over water), and allowed to stand for 10 days. At the end of this period the samples over sulphuric acid were dry enough to remove with a brush; those over water were, of course, as wet as at the start. All samples were extracted with the Truog solution in the usual manner. The results are given in Table 6. In this table, the differences between the amounts of easily-soluble phosphorus found after the treatments just described and the sum of the amounts of easily-soluble phosphorus present in the samples prior to these treatments plus the amount of phosphorus added as KH_2PO_4, are expressed as percentages of this sum. The values so obtained are referred to as Percentage Fixation values.

TABLE 6.—FIXATION, BY WET AND BY AIR-DRY FLOODED AND UNFLOODED STE. ROSALIE SOIL, OF NATIVE PHOSPHORUS EXTRACTABLE BY THE TRUOG REAGENT AND OF PHOSPHORUS APPLIED AS KH_2PO_4 SOLUTION, ON STANDING FOR 10 DAYS AT ZERO AND AT 100 PER CENT RELATIVE HUMIDITY

Conditions and duration of flooding	Percentage fixation					
	Wet soils			Air-dried soils		
	Humidity per cent			Humidity per cent		
	0	100	Diff.	0	100	Diff.
Free Drainage System— 30 days flooding with 1.0 per cent glucose solution	66.4	34.7	+31.7	65.8	67.1	−1.3
Stagnant System— 30 days flooding with water	55.7	54.4	+ 3.3	41.4	41.4	+0.0
90 days flooding with water	66.9	55.1	+11.8	58.9	54.9	+4.0
Unflooded— Original soil	—	—	—	14.6	17.2	−2.6

TABLE 7.—PERCENTAGE OF APPLIED PHOSPHORUS FIXED BY WET AND BY AIR-DRY FLOODED AND UNFLOODED STE. ROSALIE SOIL ON STANDING FOR 10 DAYS AT ZERO AND AT 100 PER CENT RELATIVE HUMIDITY

Conditions and duration of flooding	Wet soils		Air-dried soils	
	Humidity per cent		Humidity per cent	
	0	100	0	100
Free Drainage System— 30 days flooding with 1.0 per cent glucose solution	+21.7	−10.0	+45.7	+47.0
Stagnant System— 30 days flooding with water	+13.0	+ 9.7	+ 0.9	+ 0.9
90 days flooding with water	+21.4	+ 9.6	+21.2	+17.2

The salient feature of Table 6 is the very considerably increased phosphorus fixation in all the flooded samples as compared with that found for the unflooded soil. A second feature worthy of note is the fact that, under these experimental conditions, very considerable fixation of phosphorus occurred in all soil samples which previously had been flooded even when these were stored at 100 per cent relative humidity after addition of the KH_2PO_4 solution. The fact that the extent of fixation was similar, whether the added phosphate was applied to flooded soil still in the moist state or not until after the soil had been air-dried, suggests that the capacity for fixation originated in the flooding phase.

In presenting the data of Table 6 no attempt was made to differentiate between fixation of easily-soluble phosphorus native to the soil and fixation of phosphorus added as KH_2PO_4 solution. A definite answer in this connection awaits the application of the radioactive phosphorus technique, which was not available to us at the time these experiments were being conducted. A preliminary estimate of the amount of applied phosphorus fixed may be obtained, however, by calculating whether or not the amount of phosphorus fixed exceeded the total amount of easily-soluble phosphorus present in the soil before treatment. When this was done the data of Table 7 were obtained.

Examination of this table shows that the data indicate, in some instances at least, that substantial fixation of applied phosphorus had occurred. If one assumes that none of the easily-soluble organic phosphorus present in these soil samples was fixed, the values shown in Table 7 will be increased by about 8 per cent. Explanation of the apparent variations in behaviour of the different systems, and final clarification of the situation respecting the fixation of native and applied phosphorus, must await further investigation. It is believed, however, that the presently available data are strongly indicative of the possibility of the occurrence of fixation of applied phosphates in soils previously subject to conditions of flooding or of water-logging. It appears also that the degree of fixation of applied phosphorus may be considerably increased if an abundant supply of easily-decomposable organic matter is present during the flooding stage.

SUMMARY

Experimental evidence has been presented which indicates that the prolonged flooding of soils, followed by desiccation to the air-dry state under aerobic conditions, may produce undesirable effects with respect to the solubility relations of both native soil phosphorus and phosphorus added as water-soluble phosphates. The results indicate that these undesirable effects are of special importance when an abundant supply of easily-decomposable organic matter is present. The evidence suggests that the decreased solubility of the phosphorus is a result of an enhanced reactivity of the sesquioxide fraction of the soil.

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BOOK REVIEW

CATALOGUE OF INSECTICIDES AND FUNGICIDES, VOL. II: CHEMICAL FUNGICIDES AND PLANT INSECTICIDES, by D. E. H. Frear. Waltham, Mass: The Chronica Botanica Co. Ottawa, Canada: Thorburn and Abbott, Ltd. 153 pages. 1948. $5.50.

This work forms Volume 8 of the "Annales Cryptogamici et Phytopathologici" edited by Dr. Frans Verdoorn, Director of the Los Angeles State and County Arboretum.

The two volumes of the catalogue published to date are a compilation made after an extensive search of the literature and patents covering the results of testing over 10,000 candidate materials as insecticides and fungicides. Volume II deals with chemical fungicides, condensation products, plant product fungicides, miscellaneous fungicides and insecticides of plant origin. For each material tested the name, formula, synonyms, a brief note on toxicity, literature and/or patent citations are provided. As in Volume I, a coding system has been used based on the constituent chemical groups of each chemical compound. It is difficult to devise a simple coding system; therefore, in this case the author has provided, in Volume II, an alphabetical index of all compounds mentioned in the catalogue. This will be of particular advantage to the non-chemist who may have difficulty following the coding system.

This catalogue will be of interest to workers in entomology, plant pathology and agricultural chemistry and will be an invaluable aid to those engaged in screening new compounds for toxicity to insects and plant pathogens. Laborious literature and patent searches may be simplified by these two volumes.

The author points out, in the preface, that only the less commonly used materials are included in the present work. The value of the catalogue would be greatly enhanced if reference to the more important compounds now in use were included. No attempt has been made to include the new organic insecticides developed during and since World War II. It is hoped that supplementary volumes will appear which will keep this catalogue up to date, and that these volumes will review the important literature pertaining to recent developments of importance.

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LOW TEMPERATURE BREAKDOWN OF POTATOES IN STORAGE[1]

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An internal browning has frequently been observed in potato tubers, particularly of the Katahdin variety, in commercial warehouses. In order to determine whether or not this injury was the result of storage at low temperature, a joint investigation was begun in 1941 by the Division of Botany and Plant Pathology and the Division of Horticulture, Central Experimental Farm, Ottawa. It was found that tubers of certain varieties when stored for two months or longer at temperatures just above the freezing point of the tissues developed a physiological disorder which the authors have termed "low temperature breakdown".

SYMPTOMS

The chief symptom of this disorder is the development of diffuse, discoloured blotches in the flesh of the tuber (Plates I and II). In the initial stages these blotches are light reddish-brown in colour, and dark brown or almost black in advanced stages. The discoloration appears first at the stem end and may spread throughout the whole tuber. Small cavities, caused by the separation of the tissues, frequently appear in severely affected areas, but these are not confined to the central pith region as with hollow heart. In some cases the breakdown resembles late blight tuber rot, but the affected tissues are not dry and the discoloration does not originate at the surface and advance inwards as it does following late blight infection. Tissues affected by low temperature breakdown remain firm, not disintegrating as with bacterial soft rot, and there is no odour. The symptoms of low temperature breakdown are quite distinct from those produced by actual freezing of the tissues, as described by Jones *et al.* (4), Wright and Diehl (5), and Hurst (3), there being no distinct vascular necrosis, bluish-black discoloration, or leaking. The symptoms of low temperature breakdown are identical with those described by Hilborn and Bonde (2) and Folsom (1) for the type of low temperature injury that they called "internal mahogany browning".

In some varieties, notably the Katahdin, an external symptom of low temperature breakdown may be observed, a metallic, brownish-black colour appearing in irregular diffuse patches on the skin. The surface, however, is not depressed in these affected areas as it is on tubers infected with late blight. Surface discoloration is not an infallible criterion of low temperature breakdown, since it is not always present or it may be obscured by or confused with scuffing or other injuries to the skin.

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VARIETAL TESTS

In the course of these studies, six potato varieties were investigated for susceptibility to low temperature breakdown by storing them in refrigerated chambers held at 32°, 36°, and 39° F. throughout the winter months. At the end of the storage period, the tubers were cut longitudinally and examined for low temperature breakdown. The type of injury found was classified as slight, moderate, or severe, and then the following formula was applied to obtain an index, or rating, for each sample:

$$\frac{(\text{slight} \times 1)\ (\text{moderate} \times 2)\ (\text{severe} \times 3) \times 100}{\text{total number examined}} = \text{index}$$

This gave a range of indices from zero (no breakdown) to 300 (100 per cent severe breakdown).

In Table 1 the six varieties are listed in order of decreasing susceptibility to low temperature breakdown, according to the indices obtained in repeated tests. The varieties Katahdin, Chippewa and Irish Cobbler are considered to be very susceptible since they showed severe injury when stored at 32° F. and slight to moderate injury at 36° F. The variety Dooley (Rural New Yorker) is also considered to be susceptible although no injury was found after storage at 36° F. in these tests. The varieties Green Mountain and Warba are quite resistant to the disorder since only slight injury occurred at 32° F. In one test a trace of internal browning appeared in Warba tubers stored at 36° F., but it was not typical and it is doubtful if this was the result of the temperature experience.

Hilborne and Bonde (2) and Folsom (1) found that Katahdin and Chippewa tubers were severely affected by internal mahogany browning when stored at low temperatures, whereas Green Mountain tubers were not affected or only slightly so. Folsom (1) also found that predisposition to internal mahogany browning varied from one commercial or seedling variety to another, and that this predisposition is inherited.

EFFECT OF PACKING TUBERS IN MOIST SPHAGNUM MOSS

Tubers packed in moist sphagnum moss were compared with tubers not so protected, after storage at the same temperature, and found to be less affected by low temperature breakdown. For example, in Katahdin tubers stored at 32° F., the index of breakdown for those packed in moss was 82 whereas the index for the unprotected tubers was 221. Comparable results were obtained with tubers of the varieties Chippewa, Irish Cobbler, Dooley, Warba and Green Mountain. This reduction in the amount of breakdown is believed to be the result of the insulating effect of the moss. Internal temperatures of tubers, determined by inserting thermocouples, indicated an increase of from 0.5° to 1.0° F. in potatoes covered with damp moss. Hence the reduction of breakdown may be regarded as a temperature, rather than a moisture effect.

It was also noted that tubers packed in moist sphagnum showed more surface discoloration, while surface moulds developed to a less degree on them.

The protective effect of damp moss was consistently demonstrated in further tests that will be described later.

PLATE I. Three stages in development of low temperature breakdown in Katahdin tubers. *Left*, moderate; *centre*, severe; *right*, slight.

PLATE II. Low temperature breakdown in tubers of four potato varieties. *Upper left*, Dooley; *upper right*, Chippewa; *lower left*, Irish Cobbler; *lower right*, Warba.

TABLE 1.—LOW TEMPERATURE BREAKDOWN INDICES FOR SIX POTATO VARIETIES STORED AT 32°, 36° AND 39° F. FOR 7 MONTHS

Variety	Year	Low temperature breakdown index		
		32° F.	36°F.	39° F.
Katahdin	1941-42	300	0	0
	1942-43	245	41	0
	1943-44	221	0	0
	1944-45	140	20	0
	1945-46	132	0	0
	Average	208	13	0
Chippewa	1942-43	150	0	0
	1943-44	300	8	0
	Average	225	4	0
Irish Cobbler	1941-42	130	14	0
	1942-43	275	28	0
	1943-44	152	0	0
	Average	186	14	0
Dooley	1941-42	80	0	0
	1942-43	225	0	0
	1943-44	100	0	0
	Average	135	0	0
Warba	1941-42	9	0	0
	1942-43	50	0	0
	1943-44	16	12*	0
	Average	25	4*	0
Green Mountain	1941-42	16	0	0
	1942-43	33	0	0
	1943-44	0	0	0
	1945-46	5	0	0
	Average	14	0	0

* Doubtful.

LOSS IN WEIGHT BY TUBERS IN STORAGE

Calculations were made of loss in weight of tubers of six varieties under various storage treatments. These figures are recorded in Table 2.

The most striking fact found was the excessive loss in weight at 32° F. of those varieties susceptible to low temperature breakdown. For example, Irish Cobbler tubers lost 8 per cent of their weight at 32° F. whereas they lost less than 1 per cent at 36° F. and about 3 per cent at 39° F. On the other hand, tubers of the resistant varieties Green Mountain and Warba lost in the neighbourhood of 1 per cent of their weight at 32° F. As far as temperature is concerned, the general effect was that weight losses were least at lower temperatures except with varieties in which injury occurred.

The damp moss treatment was instrumental in conserving weight where the tubers were not affected by breakdown. In some exceptional cases, slight gains in the weight of the tubers were noted.

EFFECT OF CHANGING THE TEMPERATURE DURING STORAGE

Experiments were conducted to determine whether potato tubers react differently to low temperature at the beginning of their storage period than at the end of it. For this purpose, tubers of the susceptible variety Katahdin were put into storage, either dry or packed in moist sphagnum, and subjected to either an ascending or a descending temperature experience.

TABLE 2.—PERCENTAGE LOSS IN WEIGHT OF SIX POTATO VARIETIES KEPT IN STORAGE AT 32°, 36°, AND 39° F., DRY AND PACKED IN MOIST SPHAGNUM MOSS

Variety	Temperature	Dry treatment			Damp treatment		
		4 mo.	5 mo.	6 mo.	4 mo.	5 mo.	6 mo.
	° F.	%	%	%	%	%	%
Warba	32	1 9	2 2	2 8	0 3	0 6	1 4
	36	2 2	2 5	2 8	0 6	1 1	1 3
	39	2 8	3.4	3 9	*4 8	*4 4	*3 9
Dooley	32	4 4	5 5	7 0	1 4	2 5	3 5
	36	3 3	4 0	4 5	*1 3	*0 .5	0 0
	39	4 3	5 0	5 1	1 6	2 5	3 6
Katahdin	32	2 7	4 6	7 1	0 9	3 6	5 4
	36	3 6	4 6	4 5	*0 5	0 0	0 0
	39	*2 7	*1 8	*0 9	0 0	0 9	0 9
Green Mountain	32	2 9	2 4	2 9	*0 3	0 0	0 8
	36	1 6	2 0	2 4	*0 4	0 0	0 4
	39	2 1	2 6	3 1	1 2	1 7	2 1
Irish Cobbler	32	2 2	4 7	7 2	2 5	5 6	7 9
	36	1 6	2 2	2 5	*0 6	0 0	0 3
	39	1 7	2 2	2 8	0 6	1 1	1 7
		2½ mo.	3½ mo.	4½ mo.	2½ mo.	3½ mo.	4½ mo.
Chippewa	32	1 0	1 5	2 0	*0 6	*0 5	0 0
	36	1 3	1 8	2 1	*0 1	*0 5	0 0
	39	1 2	2 0	2 5	0 0	0 7	1 0

* Percentage increase in weight.

In the first test, made in 1942-43, the ascending series were held 53 days at 32° F., 50 days at 36° F., and 53 days at 39° F.; the descending series were held 53 days at 39° F., 50 days at 36° F., and 53 days at 32° F. Control samples were held at 32° F. throughout the test period. When the tubers were examined, no low temperature breakdown was found in either the dry or the damp samples of the ascending or the descending series. The dry control had a low temperature breakdown index of 125 and the damp control an index of 50 at the end of the test period. It was concluded that an exposure of longer than 53 days would be required in order to induce symptoms of low temperature breakdown.

The experiment was repeated the following year, allowing longer periods of exposure to each temperature. The ascending series were exposed to 32° F. for 67 days, to 36° F. for 63 days, and to 39° F. for 73 days; the order of these temperatures was reversed for the descending series. The control series were held at 32° F. as before.

When the tubers were examined at the end of the storage period, the indices of low temperature breakdown for the various series were as follows:

Ascending	(32°→ 39°)	dry:	78
		damp:	21
Descending	(39°→ 32°)	dry:	10
		damp:	0
Control	(32°)	dry:	221
		damp:	82

Under the conditions of this experiment, the ascending temperature experience was more detrimental than the descending experience. In other words, exposure to the critical temperature (32° F.) for 67 days at the beginning of the storage period caused more damage through low temperature breakdown than exposure to this temperature for 73 days at the end of the storage period.

The protective effect of moist sphagnum moss was strikingly demonstrated throughout this experiment. Another observation made was that tubers of the ascending series had developed a sweeter flavour than those of the descending series. Also, exposure to low temperature at the end of the storage period (descending series) retarded bud development more than the same exposure at the beginning (ascending series).

PERIODIC EXAMINATION OF TUBERS IN STORAGE

In order to determine the point of onset of low temperature breakdown and to follow the course of its development, samples of tubers were examined periodically throughout the storage period.

Test in 1943-44

In the first of these tests, Katahdin tubers, both dry and packed in moist sphagnum moss, were put into storage on October 28, 1943, and held at 32° F. Examinations of 25 tubers from each lot were made on February 9, March 7, April 7, and May 17, 1944.

At the time of the first examination, breakdown was evidently just beginning in the damp sample, but had already reached an index of 88 in the dry sample (See Table 3). The course of development of the disorder in both lots from that point is indicated by increasing indices. The protective effect of the moist sphagnum was once again demonstrated. It may also be seen from Table 3 that the dry samples had a sweeter flavour than the corresponding samples packed in moss.

Test in 1944-45

In order to determine the point of onset of breakdown more accurately and to find some means to determine or explain its occurrence, the experiment was repeated the following year, when more frequent examinations were made over the entire storage period. Katahdin tubers were put into the storage chambers on November 1, 1944, and held at 32°, 36°, and 39° F. until May 21, 1945. Half of the tubers kept at 32° F. and 36° F. were

TABLE 3.—RESULTS OF PERIODIC EXAMINATION OF KATAHDIN TUBERS STORED AT 32° F. DRY AND PACKED IN MOIST SPHAGNUM MOSS (1943-44)

Storage period (days)	Dry series		Damp series	
	Low temperature breakdown index	Flavour	Low temperature breakdown index	Flavour
105	88	M.S.[2]	4	S.S.[1]
131	136	V.S.[3]	32	S.S.
159	212	V.S.	60	S.S. to M.S.
202	221	V.S.	82	M.S.

[1]S.S. = slightly sweet. [2] M.S. = moderately sweet. [3]V.S. = very sweet.

packed in moist sphagnum, while the remainder, and those at 39° F., were left unprotected. At weekly intervals, samples of 10 tubers from each lot were removed, examined externally and internally, and tasted for sweetness. On alternate weeks, refractometer tests for soluble solids in the expressed juice were made and cooking tests were conducted.

Since only 10 tubers were used for each examination, there was considerable variation in the indices obtained for surface discoloration. However, when the indices from 24 examinations were averaged, as shown in Table 4, the relationships between temperature and moisture and surface discoloration became apparent. Surface discoloration appeared after 7 weeks on the tubers stored at 32° F., about the same time as internal breakdown, but did not subsequently progress to the same extent as the breakdown. Surface discoloration appeared to a less degree at the higher temperatures (after 13 weeks at 36° F., and after 15 weeks at 39° F.), but was not accompanied by breakdown. Thus it would seem that surface discoloration, although caused by exposure to low temperatures, is independent of the breakdown. It was also noted that more surface discoloration developed in samples packed in moist sphagnum moss than in the dry samples.

The growth of saprophytic moulds on surface wounds was greatest on tubers stored at 39° F. and least on those stored at 32° F. (Table 4). It seems probable that temperature, rather than the condition of the tubers, was the factor governing the development of these fungi. Moulds developed less extensively on tubers packed in moist sphagnum than on those stored dry, suggesting that the moss had a retarding effect despite the more favourable conditions of humidity which it provided.

The first internal symptoms of low temperature breakdown were found at the 51-day examination in the tubers stored dry at 32° F. (Figure 1), and at 85 days in the tubers packed in moss at this temperature. The indices of breakdown for both lots appeared to increase rapidly after onset to a near maximal point, then only slightly thereafter, but the samples were too small to give a smooth progress curve. A trace of breakdown appeared, at 36° F., after 177 days in the dry samples and after 184 days in the damp samples. No breakdown developed in the tubers stored at 39° F. during the test period (201 days).

TABLE 4.—INDICES OF SURFACE DISCOLORATION AND SURFACE MOULDS ON KATAHDIN TUBERS STORED UNDER VARIOUS CONDITIONS, BASED ON 24 PERIODIC EXAMINATIONS OF 10-TUBER SAMPLES

Storage temperature, ° F.	Storage moisture	Surface discoloration (average index)	Surface moulds (average index)
32	Dry	28	57
32	Damp	40	50
36	Dry	18	64
36	Damp	22	40
39	Dry	3	82

The trend of the refractometer readings for soluble solids is shown in Figure 1. It is assumed that the increments mainly represent increase in sugar accumulation or production from starch under low temperature conditions. The trend was distinct for each temperature, and, throughout, the dry samples gave slightly higher readings than the corresponding damp ones. At the lowest temperature (the one that induced the earliest onset and the greatest amount of breakdown) the greatest increase in sugar was found. As indicated on the graph (Figure 1), breakdown commenced at a refractometer reading above 9 per cent. At this point the raw tubers became definitely sweet to the taste.

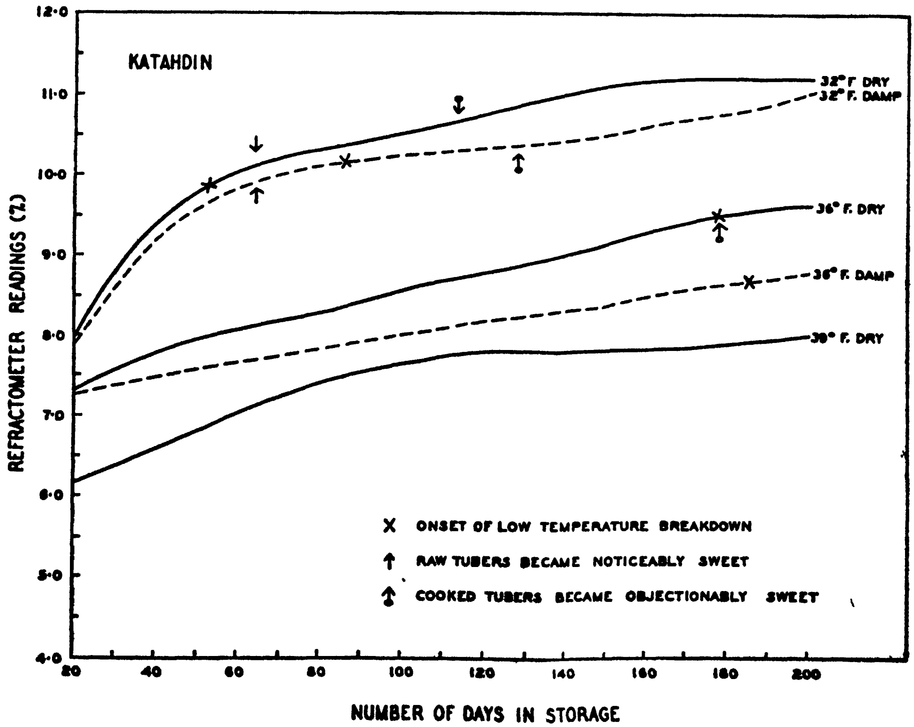

FIGURE 1. The respective trends in concentration of soluble solids in the expressed juice of Katahdin tubers held at 32°, 36°, and 39° F., either dry or packed in moist sphagnum moss for 201 days (1944-45). The point of onset of low temperature breakdown and changes in flavour are also indicated.

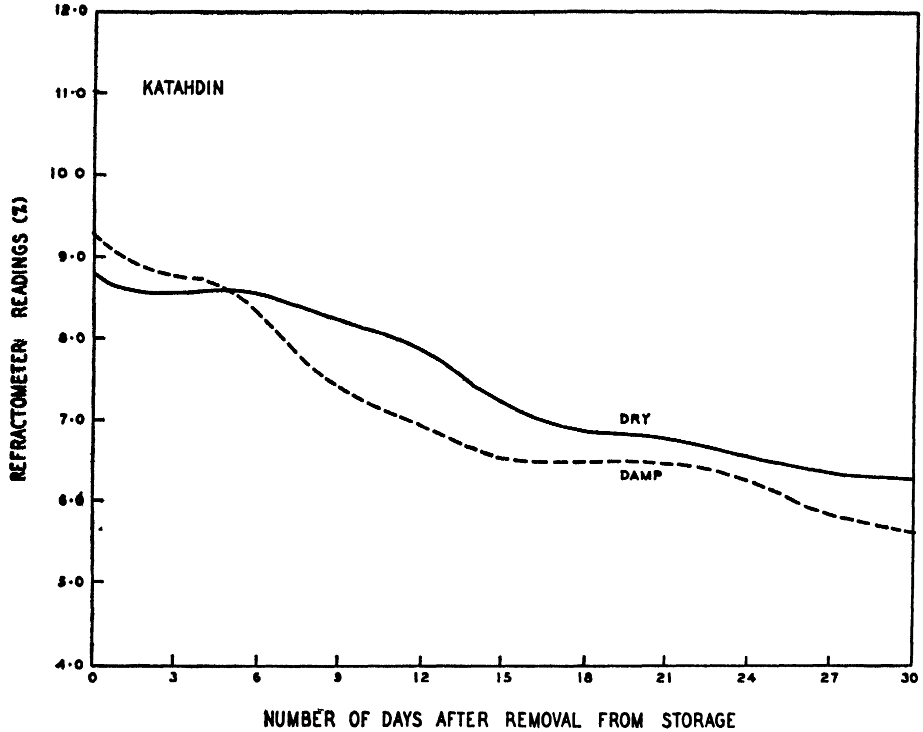

FIGURE 2. Trends in concentration of soluble solids in expressed juice of Katahdin tubers held at 65° F. and 95 per cent R.H. for 30 days following 91 days in storage at 32° F.

The cooking tests revealed no detectable difference in sweetness between samples for the first 64 days in storage, in spite of the fact that extreme differences in refractometer readings were found. After 78 days of storage, all material except that at 39° F. was sweet, the 32° F. sample more so than the 36° F. sample. The 32° F. dry sample became objectionably sweet after 115 days of storage, with a refractometer reading of 10.8 per cent. The 32° F. damp sample became objectionable when cooked at 125 days with a reading of 10.2 per cent, and the 36° F. dry sample at 175 days with a reading of 9.5 per cent. The 36° F. damp and the 39° F. dry samples were still of satisfactory quality at the end of the storage period (201 days).

One interesting fact revealed by the cooking tests was that tubers that showed the slightest sign of breakdown in the raw state turned black, at least in the affected portions, either during cooking or when allowed to stand after cooking. Thus prolonged exposure to low temperature during storage might well be one of the factors responsible for the undesirable discoloration so common in cooked potatoes.

After 78 days in storage at 32° F., some tubers were kept at room temperature for 3 days and then cooked. It was found that the sweetness still persisted. To ascertain whether or not the sugar concentration could still be decreased, tubers that had been stored at 32° F. for 91 days were kept at room temperature for a month during which refractometer read-

ings were taken regularly. The results, as illustrated in Figure 2, indicated that the sugar concentration can still be decreased, even at this stage of storage, either through respiration or reconversion to starch, or both. No cooking test was conducted on this material, but the raw tubers were found to be only slightly sweet on the 15th day. It is a curious fact that while the sample stored in damp moss had a higher concentration of sugar than the dry sample when taken from storage, the decrease in sugar in the damp sample took place at a more rapid rate, resulting in a lower concentration that that of the dry sample from the 7th to the 30th day.

The outstanding conclusion that can be drawn from the data obtained from the periodic examinations in the 1944-45 tests is that, at least in the Katahdin variety, there is a definite correlation between the incidence of low temperature breakdown and the sugar content of the tubers as indicated by the refractometer and flavour tests.

Test in 1945-46

The periodical examinations were repeated in 1945-46 with the variety Katahdin in order to further ascertain the relationship between low temperature breakdown and sugar content of the tubers. The resistant variety Green Mountain was also used for comparison. Tubers of both varieties were put into storage chambers on November 15, 1945 (after 6 weeks in common storage), and held at 32°, 36°, and 39° F. until May 11, 1946. The damp moss treatment was not used in this test. Examinations were made at 2-week instead of weekly intervals, but larger samples (60 tubers) were taken each time with a view to obtaining more consistent data on the development of breakdown. Observations made in the course of this test are summarized in Tables 5, 6, and 7.

Surface discoloration developed earliest and to the greatest extent in Katahdin tubers stored at 32° F., and latest and to the least extent in those stored at 39° F. No surface discoloration developed in Green Mountain tubers stored at any of the three temperatures. In both varieties the growth of moulds on surface wounds varied directly with the temperature, again indicating that temperature had a more direct effect than the condition of the tubers on the development of these saprophytic fungi. Moulds developed more extensively on Katahdin tubers than on Green Mountain tubers stored at the same temperature.

The flavour tests indicated that tubers of both varieties stored at 32° F. rapidly developed sweetness, those at 36° F. more slowly and to a less degree, while those at 39° F. did not become sweet at all. In each treatment the Green Mountain tubers tasted sweeter than the Katahdin tubers stored under the same conditions.

The increase in sweetness, indicating accumulation of sugar presumably derived from starch, was accompanied by an increase in soluble solids, as indicated by the refractometer readings taken on samples of juice expressed from the tubers. The trends of the refractometer readings throughout the storage period are shown in Figure 3. The trends were distinct for each temperature, and the reading for Green Mountain tubers was higher, in practically every case, than the corresponding reading for Katahdin tubers.

TABLE 5.—RESULTS OF PERIODIC EXAMINATION OF KATAHDIN AND GREEN MOUNTAIN TUBERS STORED AT 32° F. (1945-46)

Storage period (days)	Katahdin					Green Mountain				
	Surface dis-coloration index	Surface moulds index	Flavour	Refracto-meter reading (%)	Low temperature breakdown index	Surface dis-coloration index	Surface moulds index	Flavour	Refracto-meter reading (%)	Low temperature breakdown index
0	—	—	—	4.9	0	—	—	—	4.8	0
16	—	—	—	6.0	0	—	—	—	6.8	0
31	—	—	—	8.2	0	—	—	—	8.4	0
45	—	—	—	9.4	0	—	—	—	9.1	0
59	0	52	S.[1]	9.0	2	0	35	V.S.[2]	10.5	0
73	0	28	S.	9.0	0	0	27	V.S.	10.2	0
87	0	27	S.	9.0	23	0	15	V.S.	10.4	0
101	27	73	S.	9.8	35	0	10	V.S.	10.6	0
115	50	88	S.	9.2	55	0	20	V.S.	10.0	0
129	75	78	V.S.[2]	10.2	126	0	13	V.S.	9.9	2
143	113	103	V.S.	9.7	93	0	10	V.S.	9.8	5
178	152	111	V.S.	10.3	132	0	27	V.S.	9.9	0

[1] S. = Sweet. [2] V.S. = Very sweet.

TABLE 6.—RESULTS OF PERIODIC EXAMINATION OF KATAHDIN AND GREEN MOUNTAIN TUBERS STORED AT 36° F. (1945-46)

Storage period (days)	Katahdin					Green Mountain				
	Surface discoloration index	Surface moulds index	Flavour	Refractometer reading (%)	Low temperature breakdown index	Surface discoloration index	Surface moulds index	Flavour	Refractometer reading (%)	Low temperature breakdown index
0	—	—	—	4.9	0	—	—	—	4.8	0
16	—	—	—	6.2	0	—	—	—	7.8	0
31	—	—	—	6.7	0	—	—	—	7.9	0
45	—	—	—	6.9	0	—	—	—	7.6	0
59	0	47	N.S.[1]	6.8	0	0	25	S.S.	7.7	0
73	0	52	S.S.[2]	6.6	0	0	45	S.S.	7.2	0
87	0	17	S.S.	6.6	0	0	33	S.S.	7.4	0
101	0	32	S.S.	6.8	0	0	48	S.S.	7.1	0
115	27	73	S.S.	7.0	0	0	13	S.S.	7.8	0
129	55	75	S.S.	7.0	0	0	5	S.S.	7.4	2 (?)
143	78	78	S.S.	6.2	0	0	23	N.S.[1]	6.4	0
178	39	48	S.S.	7.6	0	0	4	S.[3]	7.1	0

[1] N.S. = Not sweet. [2] S.S. = Slightly sweet. [3] S = Sweet.

TABLE 7.—RESULTS OF PERIODIC EXAMINATION OF KATAHDIN AND GREEN MOUNTAIN TUBERS STORED AT 39° F. (1945-46)

Storage period (days)	Katahdin					Green Mountain				
	Surface dis-coloration index	Surface moulds index	Flavour	Refracto-meter reading (%)	Low temperature breakdown index	Surface dis-coloration index	Surface moulds index	Flavour	Refracto-meter reading (%)	Low temperature breakdown index
0	—	—	—	4.9	0	—	—	—	4.8	0
16	—	—	—	5.8	0	—	—	—	6.2	0
31	—	—	—	6.2	0	—	—	—	6.8	0
45	—	—	—	6.0	0	—	—	—	7.0	0
59	0	142	N.S.[1]	6.4	0	0	51	N.S.[1]	7.0	0
73	0	117	N.S.	6.2	0	0	30	N.S.	6.6	0
87	0	83	N.S.	6.2	0	0	30	N.S.	6.8	0
101	0	105	N.S.	6.2	0	0	20	N.S.	6.6	0
115	15	55	N.S.	6.7	0	0	37	N.S.	7.0	0
129	33	55	N.S.	6.4	0	0	65	N.S.	6.8	0
143	53	47	N.S.	6.3	0	0	27	N.S.	6.8	0
178	22	52	N.S.	6.7	0	0	53	N.S.	6.9	0

[1] N.S. = Not sweet.

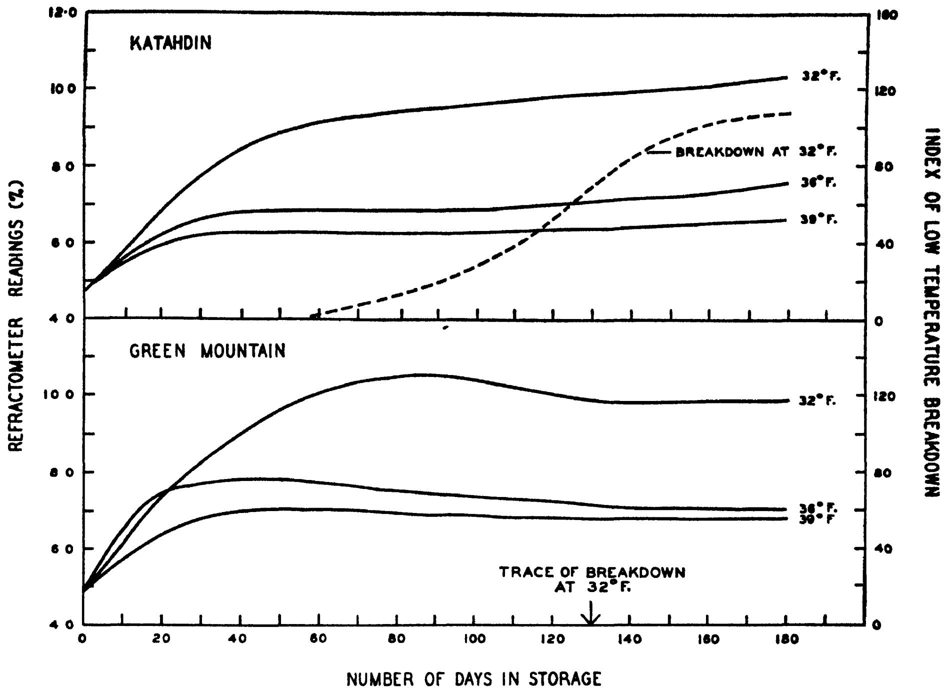

FIGURE 3. Trends of soluble solids concentration and low temperature breakdown in Katahdin and Green Mountain tubers during 178 days in storage at 32°, 36°, and 39° F. (1945-46).

Severe low temperature breakdown developed only in Katahdin tubers stored at 32° F. (Tables 5, 6, and 7). The first evidence of breakdown in this variety appeared at 59 days, and the trend of its development is shown in Figure 3. The refractometer reading for the Katahdin tubers at 32° F. was 9 0 per cent when breakdown commenced, while samples stored at 36° and 39° F. did not reach this level at any time during the test. This confirms the observation made in the previous test that low temperature breakdown and sugar concentration in Katahdin tubers are correlated. However, a high concentration of sugars is not always accompanied by breakdown. Tubers of the resistant variety Green Mountain gave consistently higher refractometer readings throughout than did the Katahdin tubers, yet only a trace of breakdown developed in these, and that after 129 days in storage at 32° F.

OTHER INTERNAL DISORDERS

In the course of these experiments, various other internal disorders were encountered, but none could be attributed to the low temperature experience of the tubers. The disorders included stem-end browning, vascular necrosis, bacterial soft rot, Fusarium dry rot, and hollow heart. Tubers severely affected by low temperature breakdown were ultimately invaded by typical storage rot organisms. Careful notes were taken on the incidence of hollow heart, but it was found to be independent of the storage experience.

EFFECT OF STORAGE ON SUBSEQUENT GROWTH

With seed potatoes, it is vitally important to know what the effect of the storage experience will be on subsequent germination, growth, and yield. For this reason, these storage tests were followed by field tests in order to obtain this information.

Bud Development During Storage

At the time of the final examination of each lot of tubers in storage, particular attention was paid to the condition of the buds. The observations on bud development at the end of the 1942-43 storage test are shown in Table 8; essentially the same conditions were observed in other years. In all varieties, the eyes of tubers stored at 32° F. were still dormant at the end of the storage period. The buds of some of the tubers of the varieties Katahdin and Irish Cobbler (which are very susceptible to low temperature breakdown) were dead when examined. Tubers of most of the varieties remained dormant at 36° F., but none of the buds was killed. Buds developed slightly on tubers of all varieties stored at 39° F. In general, the buds on tubers packed in moist sphagnum moss were more advanced than those on corresponding tubers stored dry. The increase in moisture provided by the moss as well as the slightly higher temperature noted previously would favour bud development.

Germination in the Field

The percentage of germination in planted tubers of those varieties susceptible to low temperature breakdown was drastically reduced by storage at 32° F., as indicated in Table 8, whereas it was essentially normal for the resistant varieties Warba and Green Mountain. Tubers of all varieties stored at 36° F. germinated equally as well as those stored at 39° F.

Growth of Plants

The storage experience of the tubers had a marked effect on the growth of the plants. After storage under conditions conducive to low temperature breakdown, tubers of susceptible varieties produced an irregular stand of plants, many of which were stunted or spindly. The irregularity in the size of these plants was evidently the result of retarded germination and of early decay of the seed pieces. Tubers of resistant varieties produced normal plants regardless of the storage conditions.

Yield of Tubers

Storage at low temperature reduced the yield in those varieties susceptible to low temperature breakdown in two ways: fewer plants developed from the sets planted; the plants that did grow were subnormal. In Table 8, the yield data for the 1942-43 planting are expressed in two ways: the yields given on the basis of pounds per hill indicate the differences in the crop due to the differences in vigour of the plants; the yields given on the basis of pounds per 100 sets planted indicate the combined effect of germination and vigour.

While these plantings were not replicated each year to compensate for soil differences, the results obtained in four different growing seasons

TABLE 8.—GERMINATION AND YIELD DATA ON TUBERS OF SIX VARIETIES PLANTED AFTER 7 MONTHS' STORAGE AT 32°, 36°, AND 39° F. DRY AND PACKED IN MOIST SPHAGNUM MOSS (1942-43)

Variety	Storage temperature, ° F.	Storage moisture	Condition of eyes	Germination (%)	Vigour of plants	Yield	
						Lb. per plant	Lb. per 100 sets
Katahdin	32	Dry	Dormant or dead	50.2	Poor	0.7	20
		Damp	Dormant or dead	41.7	Fair	1.0	40
	36	Dry	Dormant	96.1	Fair	0.6	43
		Damp	Dormant	94.0	Normal	0.8	63
	39	Dry	Very slightly budded	92.5	Normal	0.7	54
		Damp	Very slightly budded	98.7	Normal	0.8	73
Chippewa	32	Dry	Dormant	92.8	Poor	0.7	49
		Damp	Dormant	99.0	Poor	0.8	67
	36	Dry	Dormant	98.0	Normal	0.8	65
		Damp	Dormant	100.0	Normal	1.1	89
	39	Dry	Slightly budded	98.0	Normal	0.9	64
		Damp	Slightly budded	100.0	Normal	1.2	95
Irish Cobbler	32	Dry	Dormant or dead	37.9	Poor	0.9	42
		Damp	Dormant or dead	47.2	Poor	1.2	45
	36	Dry	Dormant	95.3	Fair	0.8	68
		Damp	Dormant	96.0	Fair	0.9	82
	39	Dry	Slightly budded	100.0	Normal	0.9	75
		Damp	Slightly budded	99.3	Normal	1.0	85
Dooley	32	Dry	Dormant	75.0	Poor	0.7	49
		Damp	Dormant	86.0	Poor	1.0	78
	36	Dry	Dormant	97.0	Fair	0.8	73
		Damp	Slightly budded	100.0	Fair	0.8	66
	39	Dry	Slightly budded	93.0	Normal	0.9	82
		Damp	Slightly budded	100.0	Normal	1.1	110
Warba	32	Dry	Dormant	96.6	Fair	1.1	106
		Damp	Dormant	99.3	Fair	1.1	95
	36	Dry	Dormant	99.3	Normal	1.2	120
		Damp	Dormant	100.0	Normal	1.1	93
	39	Dry	Slightly budded	99.3	Normal	1.3	115
		Damp	Slightly budded	100.0	Normal	1.0	90
Green Mountain	32	Dry	Dormant	98.0	Fair	1.3	116
		Damp	Dormant	100.0	Normal	1.2	106
	36	Dry	Dormant	100.0	Normal	1.1	96
		Damp	Very slightly budded	97.0	Normal	1.3	98
	39	Dry	Very slightly budded	100.0	Normal	1.2	112
		Damp	Slightly budded	98.0	Normal	1.3	123

were quite consistent and permit certain conclusions to be drawn. Tubers of varieties susceptible to low temperature breakdown that had been stored at 32° F. produced the lowest yield per plant as well as total yield, while those stored at 39° F. produced the highest yields. The yields following storage at 36° F. were close to those following storage at 39° F. The resistant varieties Warba and Green Mountain gave comparable yields following storage at all three temperatures used. In general, tubers that had been packed in moist sphagnum moss gave higher yields at all temperatures than those that had not been protected. This was particularly true of the susceptible varieties.

In two of the field tests, half of the tubers in each lot was kept at room temperature for one week before planting while the other half was left in the storage chambers until the day they were planted. Slightly higher yields were obtained in most cases from the tubers that were planted immediately on removal from storage. The difference was possibly due to deterioration of the tubers (particularly those injured by low temperature) by secondary rots developing at the higher temperature. In actual practice, this increase in yield might not be so important as the earlier maturity derived from holding seed potatoes at warmer temperatures before planting to promote sprout development.

Hilborne and Bonde (2) observed that reduced stands and yields resulted when Katahdin and Chippewa tubers affected by low temperature injury were planted in the fields.

DISCUSSION

These investigations have revealed that tubers of certain potato varieties may be seriously damaged by prolonged exposure to temperatures which are not low enough actually to freeze the tissues. Such exposure can be injurious to both table stock and seed potatoes: Table stock may be rendered objectionable in both appearance and flavour; seed potatoes may germinate poorly and produce subnormal plants and a reduced yield.

The ideal storage temperature for most varieties appears to be 36° F. At this temperature little if any breakdown occurs, yet there is a minimum loss in weight. Sprouts will not develop too rapidly at 36° F., yet they are not killed or retarded too much for seed purposes. Tubers can be stored at 36° F. for long periods without becoming objectionably sweet, so this temperature should be satisfactory even for table stock potatoes. Every effort should be made to store seed potatoes at temperatures as near 36° F. as possible, and definitely not lower than that for any length of time.

The temperature in some common storage buildings, both commercial and domestic, is allowed to fall below 36° F. and to remain there for periods sufficiently long for low temperature breakdown to develop in susceptible varieties of potatoes. As shown in these studies, an exposure to 32° F. of two months' duration at any time in the storage life of the tubers is sufficient to induce breakdown in susceptible varieties, such as Katahdin, Chippewa, Irish Cobbler, and Dooley. The resistant varieties, such as Green Mountain and Warba, will withstand this temperature much longer without injury.

No differences were found between tubers of the various varieties that would account for the differences in susceptibility to low temperature breakdown. This disorder was found to occur in Katahdin tubers when the cells had a high sugar content, as indicated by taste and refractometer tests, but Green Mountain tubers developed even higher sugar concentrations without suffering injury. A comparison of respiration rates in resistant and susceptible varieties at different temperatures might throw some light on the problem. It is also possible that enzyme action might be involved in the development of the disorder.

The fact that tubers affected by low temperature breakdown turned dark during or after cooking, suggests that prolonged exposure to low temperature may be one of the causes of blackening in cooked potatoes.

The protective effect of moist sphagnum moss is interesting from the experimental standpoint, but this treatment is not likely to prove a practical means of preventing low temperature breakdown in storage. However, the results obtained do indicate the advantage of maintaining a high relative humidity throughout the storage life of potatoes.

SUMMARY

1. A physiological disorder termed "low temperature breakdown" occurs when certain potato varieties are stored at temperatures just above the freezing-point of the tissues. The symptoms of this disorder are: (*a*) discoloured blotches in the flesh of the tuber varying from light reddish-brown to dark brown, and (*b*) a metallic, brownish-black colour appearing in diffuse patches on the skin.

2. The following varieties were tested and are listed in order of decreasing susceptibility to low temperature breakdown: Katahdin, Chippewa, Irish Cobbler, Dooley, Green Mountain and Warba. The last two varieties are highly resistant to the disorder.

3. Tubers packed in moist sphagnum moss were injured less when stored at low temperature than tubers not so protected. Surface moulds developed to a less degree on tubers packed in sphagnum.

4. Tubers of susceptible varieties lost weight excessively at 32° F. Loss in weight in resistant varieties varied directly with the temperature.

5. Exposure to 32° F. for two months at the beginning of the storage period was more deleterious to Katahdin tubers than similar exposure at the end of the storage period.

6. Periodic examinations of Katahdin and Green Mountain tubers stored at 32°, 36°, and 39° F. revealed that:

(*a*) Low temperature breakdown appeared in Katahdin tubers after 2 months at 32° F. and after 6 months at 36° F. A slight amount of breakdown appeared in Green Mountain tubers after 4½ months at 32° F.

(*b*) Low temperature breakdown in Katahdin tubers was associated with high sugar concentrations, as indicated by refractometer tests. Green Mountain tubers showed even higher sugar concentrations, however, without showing symptoms of breakdown.

(*c*) Surface discoloration was most severe on Katahdin tubers stored at 32° F. and did not develop on Green Mountain tubers.

(*d*) The growth of moulds on surface wounds varied directly with the storage temperature.

(*e*) Tubers stored at 32° F. rapidly developed a sweet flavour; tubers at 36° F. were less sweet, and those at 39° F. did not become sweet. Green Mountain tubers tasted sweeter than Katahdin tubers stored under the same conditions.

(*f*) Tubers affected by low temperature breakdown turned black when cooked or allowed to stand after cooking.

7. Low temperature retarded or inhibited bud development in tubers of varieties susceptible to breakdown. Such tubers germinated poorly when planted, and produced subnormal plants with a correspondingly reduced yield.

8. A storage temperature of 36° F. is considered the best from all standpoints for the storage of potatoes, particularly if they are to be used for seed.

ACKNOWLEDGMENT

These investigations were undertaken at the suggestion of, and in collaboration with H. N. Racicot, Division of Botany and Plant Pathology, Central Experimental Farm, Ottawa. The writers are indebted to him for his valuable suggestions and participation, particularly in the early stages of the work.

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EXPERIMENTS WITH RADIOPHOSPHORUS ON THE UPTAKE OF PHOSPHORUS BY WHEAT[1]

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The introduction of the tracer technique in the study of soil chemistry and plant nutrition has provided a new and valuable method for attacking these difficult fields of research. In particular, the tracer technique using radiophosphorus has many useful applications in studying the problems associated with chemical reactions of phosphorus in soil and fertilizer, and with the uptake of phosphorus by the growing plant.

The use of phosphatic fertilizers on crops in Saskatchewan has become common practice in recent years. Results of some experimental work have been reported (4) and further experiments have led to the conclusion that very general use of phosphate fertilizer on wheat and other crops is a requirement in obtaining the highest yields on most Dark Brown and Black soils (5) of the region. There are some 24 million acres of such soils under cultivation, a little over a third of the acreage being sown to summer-fallow wheat each year. Present recommendations are to use phosphate fertilizer on summerfallow crops only, since other crop land generally gives little or no response. Considering that most of the 8 or 10 million acres of summerfallow may eventually be fertilized, and that the average increase in yield of wheat obtained is about 5 bushels per acre, the growing interest in phosphatic fertilizers may be readily understood.

The presently recommended fertilizer treatment is 11-48-0 at 30 to 60 pounds per acre. In spite of the fact that a nitrogen-carrying fertilizer is used, the element nitrogen seems to have no direct effect in producing the increased yield (4), and the advantage of 11-48-0 over other phosphates seems to be due to the greater efficiency of ammonium phosphate as a carrier of phosphorus when applied to the neutral or alkaline soils common to this area.

BRIEF REVIEW OF RESULTS OF RADIOPHOSPHORUS WORK AT THE UNIVERSITY OF SASKATCHEWAN

Results of experiments using radiophosphorus have been reported by Spinks and Barber (7, 8), Barber, Mitchell and Spinks (2), and by Spinks, Dion, Reade and Dehm (9). A review of literature is given in these publications and also the techniques developed in using radiophosphorus as a tracer element in studying the reactions of applied phosphorus in soil and plant.

Some of the more important conclusions reported in the above papers are as follows:

1. That the wheat plant takes up phosphorus from soil and fertilizer until maturity, but that the main absorption of the fertilizer phosphorus takes place well before the plant matures.

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[1] Contribution from Department of Soils, University of Saskatchewan, Saskatoon. Presented at meeting of Soils Subject Division, Agricultural Institute of Canada, Guelph, Ont., June, 1948.

[2] Associate Professor of Soils.
[3] Professor of Chemistry.
[4] Professor of Soils.

2. Where small applications of fertilizer were used on an Elstow silt loam soil (25 lb. per acre 11-48-0 in these experiments) about 22 per cent recovery by the plant was obtained. The per cent recovery tends to decrease as the amount of application is increased, although the actual amount of phosphorus taken up from the fertilizer may increase.

3. In earlier stages of growth, the larger amount of phosphorus taken up by the plant is obtained from the fertilizer; thereafter the soil supplies the greater portion.

4. In some cases, the fertilized wheat may use greater amounts of soil phosphorus than the unfertilized crop where light applications (25 lb. 11-48-0 per acre) are the practice. However, for heavier applications the reverse appears to hold true (9).

Barber (1) also studied the effect of time of application on phosphorus uptake, and on growth. His data were obtained in the greenhouse and indicate that applying the fertilizer at the two- and four-week stage increased the uptake of fertilizer phosphorus, but that there was a tendency for less increase in growth as compared to application with the seed.

These results are summarized in Table 1. They indicate that the practice of applying the fertilizer at seeding gives better yield results than would applications at any later stage of growth. This is fortunate since the most practicable time to apply fertilizer is when the grain is being seeded. According to Gericke (3) the critical time in phosphorus nutrition for the wheat plant appears to be during the first few weeks after emergence. It is possible that the importance of early supplies of phosphorus is connected with the early development of flower primordia in the young seedling. The maximum number of flowers in the spike is apparently determined at about the 4- to 6-week stage in plant development, and to have an effect on length of head and number of kernels, the necessary phosphorus must be present quite early in the plant's development.

The basic worth of the tracer method in this type of experimental work lies in the fact that the use of radiophosphorus permits the accurate identification of applied phosphorus in soils and plants. For instance, the amount of phosphorus recovered by the plant from a particular fertilizer has heretofore been estimated by comparing total phosphorus uptake by fertilized and unfertilized plants. This method does not exclude the

TABLE 1.—EFFECT OF TIME OF APPLICATION ON GROWTH AND UPTAKE OF PHOSPHORUS BY WHEAT PLANTS

(Plants harvested at 8 weeks)

Time of application	Weight of plants at 8 weeks (gm.)	Total P. in plant material (mg.)	P. in plant obtained from fertilizer (mg.)*
At seeding	3.17	9.51	2.86
Two weeks	2.67	7.93	3.03
Four weeks	2.79	8.19	3.48
Half at planting and half at four weeks	2.82	7.74	3.33
No fertilizer	2.57	5.50	—

* Difference of 0.54 mg. required for significance at 5 per cent point.

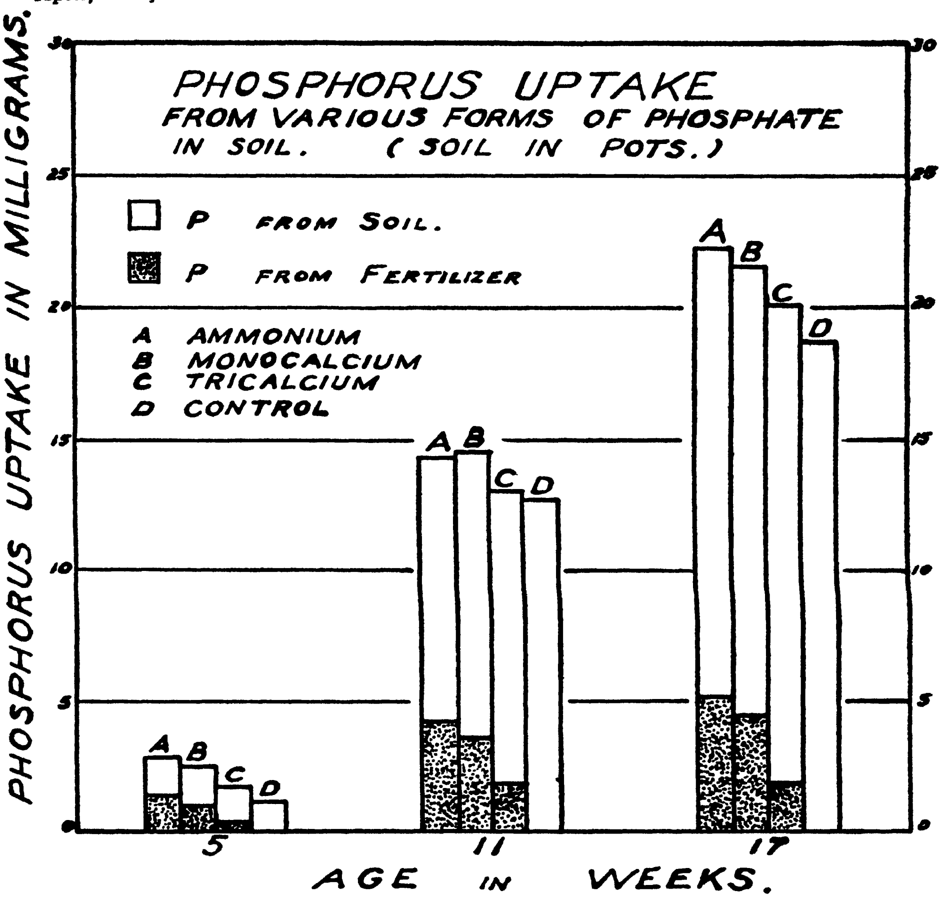

FIGURE 1. Showing uptake of phosphorus by wheat plants from several phosphate fertilizers at various stages of growth

possibility that the fertilized crop might use a different amount of soil phosphorus simply as a result of fertilization. Indeed, it appears (8) that for light applications more soil phosphorus may be taken up, but for very heavy applications, there may be less. The possibility that there may be an additional demand on the available phosphorus in some soils as a result of fertilizing with low rates of phosphate is a matter of considerable interest. In Saskatchewan and in the prairie provinces generally, light applications of from 20 to 30 pounds of 11-48-0 ammonium phosphate are usual, although larger applications are recommended.

In general, the fertilizer is applied to the summerfallow crop since stubble crops respond only in certain districts where moisture conditions are especially favourable. The average 20 to 30 pound application which the farmers are at present using will hardly balance the phosphorus requirements of the crops in the common three-year rotation of summerfallow, wheat and wheat or other grain. This, and the possibility that there may be a greater drain on the native phosphorus of the soil than had been suspected, points to a need for higher rates than are at present in use. Field experiments have shown that higher applications, on the average, give profitable increases up to 50-60 lb. per acre (6).

As previously mentioned, an ammonium phosphate appears to have a definite superiority over triple superphosphate or single superphosphates on the usually neutral to alkaline and frequently calcareous soil of this area (5). An experiment carried on in the greenhouse to test the relative availability of several forms of phosphate gives further information on this question.

Wheat was grown to the 5-week stage, to the early shot-blade (11 weeks) and to the dough stage (17 weeks) in pots fertilized with mono-ammonium, mono-calcium and tri-calcium phosphate, at rates equivalent to 25 lb. per acre of 11-48-0. The phosphates were prepared in the laboratory, and carried radiophosphorus as a tracer. The preparation of pure orthophosphates of calcium is a matter of some difficulty, and there was no assurance that the salts prepared were of a high degree of purity. However, on the basis of their analyses, it was felt that their performance in the availability trials would at least be a reflection of the quite different proportions of calcium combined with phosphorus in these two compounds,

TABLE 2.—COMPARATIVE UPTAKE OF PHOSPHORUS BY WHEAT FROM AMMONIUM PHOSPHATE, MONO-CALCIUM PHOSPHATE AND TRI-CALCIUM PHOSPHATE APPLIED TO ELSTOW SILT LOAM

Average results at 5-week stage

	$NH_4H_2PO_4$	$Ca(H_2PO_4)_2$	$Ca_3(PO_4)_2$	Unfert.	Least sig. difference at 5% point
Fert. P. taken up by plants (mg.)	1.4	1.0	0.3	—	0.1
Total P. in plants (mg.)	2.8	2.5	1.7	1.1	1.0
Soil P. in plants (mg.)	1.4	1.5	1.4	1.1	—
Weight plant material (gm.)	0.65	0.59	0.49	0.39	0.085

Averages at early shot-blade stage—11 weeks

	$NH_4H_2PO_4$	$Ca(H_2PO_4)_2$	$Ca_3(PO_4)_2$	Unfert.	Least sig. difference at 5% point
Fert. P. taken up by plants (mg.)	4.2	3.6	1.9	—	0.3
Total P. in plants (mg.)	14.4	14.5	13.1	12.8	1.2
Soil P. in plants (mg.)	10.2	10.9	11.2	12.8	1.4
Weight plant material (gm.)	4.36	4.34	3.93	3.82	0.26

Averages at dough stage—17 weeks

	$NH_4H_2PO_4$	$Ca(H_2PO_4)_2$	$Ca_3(PO_4)_2$	Unfert.	Least sig. difference at 5% point
Fert. P. taken up by plants (mg.)	5.2	4.5	1.9	—	0.4
Per cent recovery of Fert. P.	29.0	25.0	10.3	—	2.2
Total P. in plants (mg.)	22.3	21.6	20.2	18.8	2.0
Soil P. in plants (mg.)	17.1	17.1	18.3	18.8	1.8
Weight plant material (gm.)	9.01	8.91	8.71	7.77	0.32

and would give some information on the question of the availability of calcium phosphates in comparison to ammonium phosphates in a base-saturated soil.

The soil was Elstow silt loam, pH 7.1, (5) and free of excess carbonates or alkali. Six pots were grown for each treatment.

The data obtained by plant analysis at the various harvest stages are given in Table 2 and Figure 1.

These data indicate the greater availability of the phosphorus when applied in the form of mono-ammonium phosphate as compared to mono-calcium phosphate and tricalcium phosphate. In every case, the pots treated with ammonium phosphate show a significantly higher uptake of phosphorus by the wheat plant than for the mono-calcium phosphate, or the tri-calcium phosphate treatments. Tri-calcium phosphate is recognized as not being an efficient type of phosphate carrier for neutral or alkaline soils, and its low availability in this experiment serves to emphasize such a conclusion.

The comparison of results as between ammonium phosphate and mono-calcium phosphate is the most significant from the practical standpoint. The data indicate that the calcium salt has a lower availability to the plant than does the ammonium phosphate, and it appears that the previously mentioned superiority of the ammonium phosphate in field performance can be ascribed to the greater availability of the phosphorus rather than to a direct beneficial effect of nitrogen as a nutrient. There is, however, the possibility of nitrogen stimulating the plant to a higher uptake of phosphorus. Further work on this point is in progress.

At present in Saskatchewan, there is only a small tonnage of fertilizer other than ammonium phosphate used on cereals. The data in this experiment indicate that phosphate applied as ammonium phosphate is likely to prove more effective per unit of phosphorus than it would if applied in the various forms of superphosphates. This test of availability demonstrates the particular value of the tracer technique in soil chemistry and plant nutrition. The statistical analysis indicates significant differences between the amounts of fertilizer phosphorus taken up from each fertilizer at all harvest dates, while only the larger differences are significant when total phosphorus values are compared.

Field tests in progress during the summer of 1948 appear to confirm the results of these greenhouse experiments and indicate that a test such as described above may prove useful in evaluating and comparing the efficiency of the different carriers of phosphorus without resorting to extensive field trials.

SUMMARY

Further greenhouse experiments are reported using radiophosphorus in fertilizer trials on wheat. It is shown that applications of phosphorus at seeding give the best response in growth although the uptake of fertilizer phosphorus may be increased by applying the material at two or four weeks after seeding. A further experiment confirms previous observations that mono-ammonium phosphate is a particularly suitable carrier of phosphorus for the generally base-saturated soils of this region. There was

a significantly greater uptake of phosphorus from mono-ammonium phosphate as compared to mono-calcium or tri-calcium phosphates at each of three periods of growth at which the wheat was harvested. It is suggested that such a test may be useful in evaluating the availability of various carriers of phosphorus when applied to different soils.

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THE NUTRITIVE VALUE OF NITROGENOUS COMPOUNDS FOR RUMINANTS

I. THE NUTRITIVE VALUE OF UREA AS A PROTEIN SUPPLEMENT[1]

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Since the beginning of the present century numerous experiments have been carried out in Germany to determine whether or not urea and other non-protein nitrogenous substances could be used as a source of nitrogen for the nutrition of ruminants. The results were not conclusive. In more recent years considerable interest has been aroused in the United States regarding possible uses of urea in feed stuffs. The results from many investigations have been sufficiently encouraging that recommendations have been made concerning the incorporation of urea in commercial feed stuffs. For instance, the Association of American Feed Control Officials, Inc., (1) states that urea may partially replace the nitrogen of protein concentrates up to 3 per cent of the concentrates. In the same way, the Quebec Provincial Feed Board in Canada (3), has made similar recommendations.

In this paper further information has been obtained on the use of urea for ruminant feeding. No literature review is included since that has been done by other authors in papers and reviews.

In the determination of the nutritive values of nitrogenous compounds for ruminants, a number of different methods have been used. These fall into two general classes—feeding trials and metabolism or balance trials. For small laboratory animals, a technique involving carcass analysis has been used to determine the increase in nitrogen or other body nutrients resulting from a specific dietary regime. Representative animals are slaughtered at the beginning of a feeding trial and analysed. The chemical composition is assumed to represent that of the remaining animals which are slaughtered and analysed at the end of the dietary treatment. The differences between the quantities of nutrients in the animal body at the beginning and end of the trial are assumed to represent the result of the feeding system used. This technique has been applied, in conjunction with feeding trials, to large animals in the present paper.

For this experiment 30 head of grade Shorthorn beef calves, weighing approximately from 150 to 200 kilograms, and 60 sheep, weighing approximately from 20 to 35 kilograms, were used. The animals were divided as uniformly as possible into groups of five each. From each group at the beginning of the experiment, two were slaughtered and analysed. Of the remaining three, one constituted the negative control receiving a nitrogen-poor basal ration. One was the positive control receiving the same basal ration with the addition of casein to supply the nitrogen requirements of the animals. This was accompanied by the simultaneous removal of starch or oil from the ration to balance the total digestible nutrients of the casein.

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The third animal was the experimental one receiving the basal ration with the addition of sufficient urea to equal the casein in content of digestible nitrogen. In each group the consumption of T.D.N. was equalized for the three animals. The quantities of T.D.N. given were based on the weights of the experimental urea animals in each group and estimated from Morrison's standards. Digestibility coefficients of the feeds, with the exception of molasses, were determined from digestion trials by this Division. Values for molasses were taken from Morrison's tables.

Part I. Beef Calves

Procedure

For the experiment with beef calves the basal, nitrogen-poor ration consisted of timothy hay, oat straw, barley, corn starch, corn oil and molasses. A typical ration is shown in Table 1. In addition the animals received mineral and vitamin supplements to satisfy their requirements.

TABLE 1.—TYPE OF BASAL NITROGEN-POOR RATION FED TO BEEF CATTLE

(Based on average of all basal rations fed to all groups)

Feed	Per cent in ration
Timothy hay	27.0
Oat straw	22.0
Barley	8.5
Corn starch	17.5
Corn oil	7.5
Molasses	17.5

The actual proportions of the feeds varied from group to group according to the individual tastes of the animals. While this ration was not free from nitrogen, the latter was well below the maintenance requirements. This will be shown later.

At the beginning of a trial for any one group the basal ration was fed to all animals until the live weights reached a constant level. Two of each group were then killed and analysed and to the remaining three were allotted the basal ration, basal ration plus urea or basal ration with casein. The allotment was, as far as possible, at random. In some cases, animals which gave indications of being poor eaters for the basal ration were chosen for slaughter. In one case a choice was made of the negative control animal.

Following the initial slaughter the animals were weighed weekly and the necessary adjustments made in the quantities of T.D.N. and digestible nitrogen. Feeds were analysed for dry matter and nitrogen throughout the experiment. At the end of about 40 to 50 weeks of feeding, the remaining three animals in the group were slaughtered and analysed. Slaughter weights and initial "empty" live weights were made after a twenty-four hour fast and a twelve-hour deprivation of water. The animals were clipped before weighing.

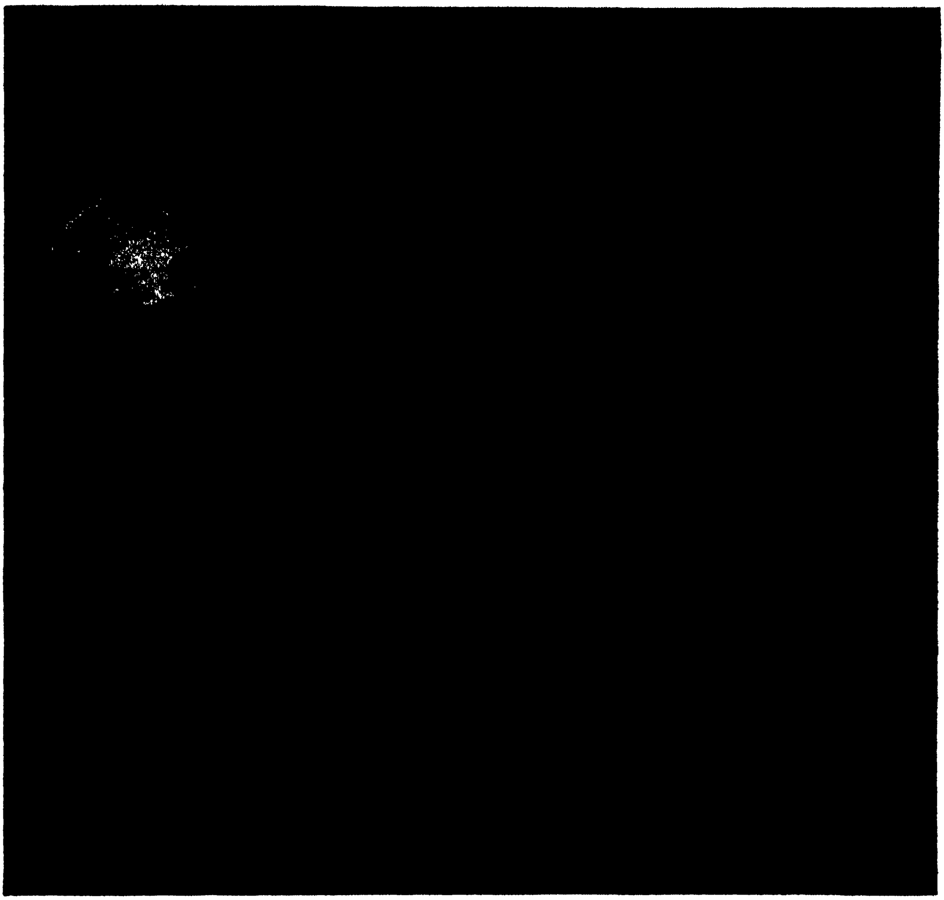

FIGURE 1.—Group "A" just prior to slaughter.
No. 1 (*left*)—Negative control.
No. 2 (*middle*)—Urea.
No. 3 (*right*)—Positive control.

The slaughter technique was carried out in the following manner. The animals were fasted for 24 hours, clipped and killed. The clipped hair was discarded in the case of the two animals slaughtered in each group at the beginning of the trial. For the remaining three animals, slaughtered at the end of the trial, it was weighed and analysed. The blood was removed through the jugular vein, weighed and analysed for dry matter, nitrogen and ash. The hide, the empty washed digestive tract, the liver and the kidneys, were weighed and analysed for dry matter, nitrogen, fat and ash. The carcass was split into halves. One-half was separated into bone and meat. Each of these portions was weighed, sampled and analysed. The head, hoofs and tail-bone were treated as one sample. A final sample called fat and tissue consisted of extraneous fat, flesh and fat from the head, and the tongue. All samples were cooled with dry ice. The compilation of all these results gave the total composition of the entire animal expressed as per cent of the "empty" live weight.

Results

The six groups of steers were numbered A to F, respectively. With groups A, C, D and E, the experiment progressed without any serious incident. In group B, the negative control died. No obvious cause was revealed by a post mortem. In group F, the experimental urea animal died near the end of the trial. It was not possible to carry out any carcass analyses and the criterion for the value of urea was based on live weight gains only. A post mortem revealed no obvious cause of death. In some groups, for short periods, it was necessary to increase the proportion of hay in the ration at the expense of some or all of the other constituents. This was done when one or more animals in a group gave indications of going off feed. Apart from this the animals remained in good health and maintained their appetites. Figure 1 illustrates group A just prior to slaughter. No. 1 was the negative control, No. 2 the urea animal and No. 3 the casein animal.

The relationship of the digestible nutrients consumed to those required is given in Table 2.

The amount consumed is the mean daily quantity throughout the trial. The amount required is based upon the mean of the initial and final weights of the animals. It will be observed that the negative control animal received more than its requirements of T.D.N. and approximately one-half to two-thirds of its maintenance requirements of digestible protein.

TABLE 2.—COMPARISON OF DAILY NUTRIENTS CONSUMED WITH DAILY NUTRIENTS REQUIRED BASED ON MEAN LIVE WEIGHTS OF ANIMALS AND MORRISON'S TABLES. BEEF ANIMALS.

Group No.	Animal No.	Ration*	Daily values in kilograms				
			T.D.N.		D.C.P.		
			Required	Consumed	Required	Consumed	Maintenance requirement
A	14K	Neg. control	3.60–4.02	3.76	0.450–0.502	0.080	0.168
	39K	Urea	3.90–4.40	3.79	0.472–0.532	0.454	0.181
	36K	Pos. control	4.05–4.65	3.81	0.448–0.548	0.420	0.191
B	33H	Urea	3.28–3.63	2.99	0.420–0.472	0.297	0.150
	34H	Pos. control	3.45–3.83	3.01	0.439–0.489	0.313	0.160
C	35H	Neg. control	3.37–3.75	3.42	0.430–0.481	0.100	0.152
	36H	Urea	3.61–4.07	3.43	0.450–0.503	0.404	0.169
	37H	Pos. control	3.83–4.33	3.41	0.468–0.528	0.400	0.180
D	40H	Neg. control	3.12–3.48	3.25	0.403–0.458	0.098	0.140
	43H	Urea	3.39–3.76	3.25	0.432–0.482	0.380	0.154
	44H	Pos. control	3.80–4.38	3.25	0.463–0.523	0.377	0.178
E	48H	Neg. control	3.40–3.79	3.43	0.433–0.483	0.098	0.156
	46H	Urea	3.64–4.09	3.42	0.453–0.508	0.399	0.169
	47H	Pos. control	3.90–4.40	3.44	0.472–0.533	0.399	0.182
F	78503	Neg. control	3.00–3.30	3.00	0.391–0.442	0.095	0.131
	78495	Urea	3.08–3.42	3.00	0.400–0.452	0.315	0.138
	78507	Pos. control	3.20–3.55	2.99	0.412–0.464	0.295	0.143

* Negative control is nitrogen-poor ration.
Urea is the same ration with urea added.
Positive control is the casein ration.

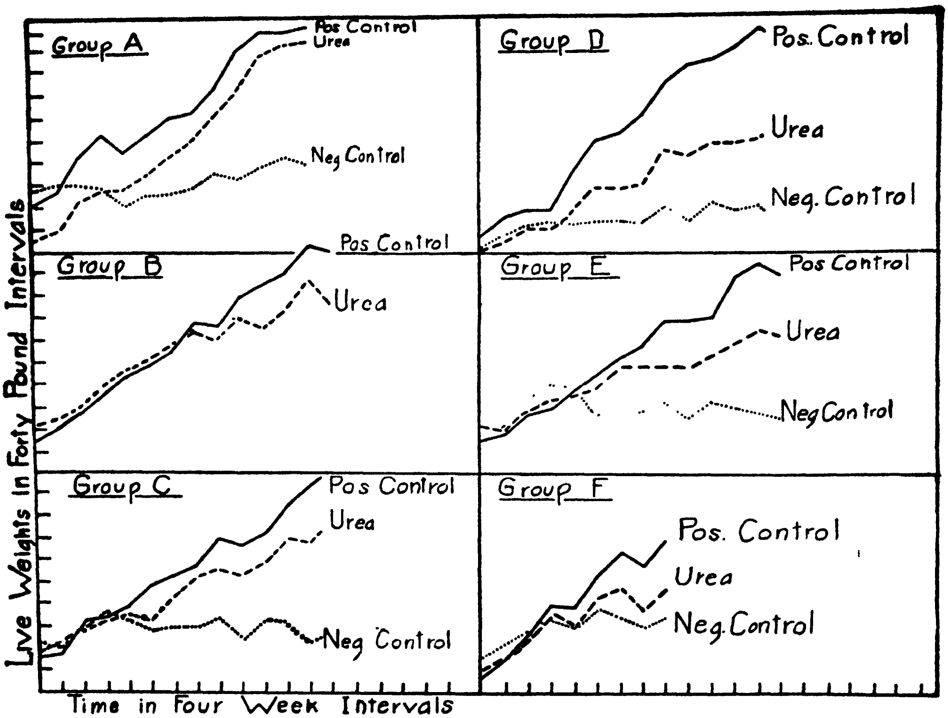

FIGURE 2. Weight increases of beef calves in the six groups.

The other two animals received amounts of T.D.N. and digestible crude protein closely approximating their requirements. In calculating the protein of the rations, the urea nitrogen was converted to its equivalent of digestible protein.

The weight changes are illustrated in Figure 2 at four-week intervals. It will be noted that the negative controls showed little change in live weight. In groups B, C, D, E and F the curve for the urea animals did not reach as high a level as that for the positive control. In group A the curves for the urea and the positive control were roughly parallel.

In Table 3 are summarized the gains in live weights and also the gains in body nutrients. Compared with the negative controls, the urea animals showed marked increases in the live weights and in the protein, fat and ash. Compared with the casein animals, with the exception of group A, the urea animal made less gains in live weight and body nutrients than the positive controls. In group A, the urea animal made a greater gain in live weight, weight of protein and weight of fat than the positive control but a smaller gain in ash.

The data for the urea and casein animals were analysed statistically. The method of paired values as described by Fisher (2) was used. The "t" values have been placed at the foot of the table. The differences between the two rations were significant for live weights and weights of protein and ash but not for fat.

In Table 4 are given the gains in total weight of carcass, and in the weights of individual carcass constituents. The urea animals compared

TABLE 3.—GAINS IN "EMPTY" LIVE WEIGHT AND BODY COMPONENTS. BEEF CALVES.

Group	Ration	Animal No.	Gains in kilograms: Empty live weights	Individual components: Protein (N × 6.25)	Fat	Ash
A	Neg. control†	14K	25	−1.2	21.5	−1.0
	Urea	39K	161	25.2	23.3	3.4
	Pos. control‡	36K	149	23.4	14.6	5.7
B	Urea	33H	120	21.4	13.8	4.3
	Pos. control†	34H	179	32.4	26.5	8.0
C	Neg. control†	35H	−6	−0.4	4.4	−0.9
	Urea	36H	65	13.9	22.3	2.0
	Pos. control‡	37H	128	24.7	31.6	4.6
D	Neg. control†	40H	28	6.7	13.9	1.6
	Urea	43H	92	14.5	38.0	1.0
	Pos. control‡	44H	145	27 8	38.6	4.0
E	Neg. control†	48H	−6	−0.1	11.8	−0.4
	Urea	46H	74	12.6	28.7	1.7
	Pos. control‡	47H	136	23.8	28.9	5.6
F	Neg. control†	78503	40	*	*	*
	Urea	78495	80	*	*	*
	Pos. control‡	78507	112	*	*	*
Means	Neg. control†		16	1.2	12.9	−0 2
	Urea		99	17 5	25.2	2.5
	Pos. control‡		142	26.4	28.0	5.6
"t" values for paired differences between urea and casein rations			3.59	3.28	0 75	10.06
Nec. "t" at P = 0 05			2.57	2.78	2.78	2.78

* Not determined for reasons given in text.
† Negative control—low nitrogen ration.
‡ Positive control—casein ration.

with the negative controls showed substantial gains. Their results were compared with those for the casein animals. The latter, with the exception of group A, had greater gains. Statistically, the gains in weights of total carcass, protein, ash and water of the casein animals were greater than those for the urea animals. The differences in fat gains were not significant.

In Table 5 are given the chemical compositions of the gains in the carcasses of the urea and casein animals. The "t" values are given at the foot of the table. Numerically, the percentages of protein, ash and water were higher for the casein animals, while the percentage of fat was lower. The differences for the protein and ash were statistically significant. While the differences in fat and water were not statistically significant, yet in groups A, C, D and E, the fat per cent was definitely higher in the urea animal with the water per cent lower. In group B the fat of the urea animal was quite low and the water correspondingly quite high. It can be concluded that the carcasses of the casein animals tended to have a higher percentage of protein and ash while the carcasses of the urea animals tended to be higher in fat and correspondingly lower in water.

TABLE 4.—GAINS IN WEIGHTS OF TOTAL CARCASSES AND OF INDIVIDUAL COMPONENTS. BEEF CALVES.

Group No.	Ration	Animal No.	Gains in kilograms					
			Total* carcass	Protein (N × 6.25)	Fat	Ash	Water	Sum of components
A	Neg. control	14K	9.2	−0.3	15.7	1.7	−3.3	13.8
	Urea	39K	83.2	15.4	16.7	2.1	48.3	82.5
	Pos. control	36K	74.8	15.1	10.9	3.4	45.9	75.3
B	Urea	33H	76.2	14.2	9.1	3.3	51.0	77.6
	Pos. control	34H	109.8	21.8	20.2	6.1	64.6	112.6
C	Neg. control	35H	4.0	−0.4	2.3	−0.9	5.0	6.0
	Urea	36H	48.0	8.1	13.8	1.7	28.2	51.8
	Pos. control	37H	89.1	16.8	18.3	3.4	54.4	92.9
D	Neg. control	40H	26.2	4.1	9.4	1.6	11.1	26.2
	Urea	43H	55.0	8.3	23.0	1.1	26.8	59.2
	Pos. control	44H	96.5	16.8	25.9	3.3	52.4	98.4
E	Neg. control	48H	2.1	−0.6	7.2	−0.7	−2.6	3.3
	Urea	46H	40.2	7.4	16.9	1.2	15.3	40.8
	Pos. control	47H	76.2	15.2	17.9	4.4	42.0	79.5
Means	Neg. control		10.4	0.7	8.6	0.4	2.6	12.3
	Urea		60.5	10.7	15.9	1.9	33.9	62.4
	Pos. control		89.3	17.1	18.6	4.1	51.8	91.7
"t" values for paired differences between urea and casein rations			3.06	3.80	1.00	6.46	3.18	—
Nec. "t" at P = 0.05			2.78	2.78	2.78	2.78	2.78	—

* Values for negative control will not be in line with gains in live weights in Table 3 due to (1) small gains or losses of live weights in negative controls, and (2) resulting magnification of error caused by an assumed original composition.

DISCUSSION

It is, therefore, evident that the animals receiving urea utilized it for the production of meat. It was not utilized as well as casein. In practice urea would not be fed as the sole source of nitrogen. Its value in this experiment relative to casein would not necessarily be the same as its relative value when incorporated into a mixed protein ration. In a further series of trials this point is being investigated.

Part II. Sheep

The procedure with sheep was similar to that used for steers, except that separate consideration was given to the nitrogen in the wool growth. The sheep were sheared prior to the experiment and prior to slaughtering. The basal ration was slightly different from that fed to the steers. Its type is given in Table 6.

It was composed of oat straw, turnips, apple pomace, flax bolls, oat hulls, corn meal, corn starch and corn oil, together with mineral and vitamin supplements.

TABLE 5.—CHEMICAL COMPOSITION OF GAINS IN CARCASSES OF ANIMALS ON UREA AND CASEIN RATIONS. BEEF CALVES.

Group No.	Ration*	Animal No.	Chemical composition of gains: Protein (N × 6.25)	Fat	Ash	Water	Sum of per cent
			%	%	%	%	
A	Urea	39K	18.6	20.0	2.4	58.1	99.1
	Casein	36K	20.1	14.6	4.6	61.4	100.7
B	Urea	33H	18.7	12.0	4 4	67.0	102.1
	Casein	34H	19.8	18.4	5.5	58.8	102.5
C	Urea	36H	16.9	28.8	3.6	58.9	108.2
	Casein	37H	18.8	20.5	3.8	61.0	104.1
D	Urea	43H	15.1	41.8	2.0	48.7	107.6
	Casein	44H	17.4	26.9	3.4	54.3	102.0
E	Urea	46H	18.5	42.1	3.0	38.0	101.6
	Casein	47H	19.9	23.4	5.8	55.1	104.2
Means	Urea	—	17.6	28.9	3.1	54.1	103.7
	Casein	—	19.2	20.8	4.6	58.1	102.7
Difference			+1.6	−8.1	+1.5	+4.0	—
"t" values (Nec. "t" at P = 0.05 is 2.78)			7.85	1.89	3.45	0.98	—

* Casein animals—positive controls.

This experiment was unsatisfactory. It was impossible to induce the sheep to eat much more than the maintenance requirements. The result was that with the exception of a few cases where casein was fed, the animals showed losses in weight and body constituents. Criteria, under these circumstances, would be firstly, the ability of different rations to prevent losses in body nutrients and secondly, the amount of protein laid down in the wool growth. These are of limited significance. The results support those with steers and have, therefore, been recorded.

During the progress of the experiment, one whole group and the negative control in a second group had to be removed from the experiment. This was due either to failure in food consumption or death. There were

TABLE 6.—TYPE OF BASAL RATION FED SHEEP
(Based on daily mean of all rations for all animals)

Feed	Per cent in ration
Oat straw	25
Turnips	42
Apple pomace	5
Flax bolls	2
Oat hulls	6
Corn meal	6
Corn starch	10
Corn oil	4

left, therefore, 10 groups of 3 each and one group of two animals—the urea and the positive control. These have been numbered 1 to 11 in the experiment.

In Table 7 are given the mean daily consumption of T.D.N. and digestible protein compared with Morrison's standards for growing and fattening sheep. The weights of the animals were the average of the initial

TABLE 7.—COMPARISON OF DAILY NUTRIENTS CONSUMED WITH DAILY REQUIREMENTS BASED ON MEAN LIVE WEIGHTS OF ANIMALS AND MORRISON'S TABLES SHEEP.

Group No.	Animal No.	Ration	Daily values in kilograms					
			T.D.N.			D.C.P.		
			Required		Consumed	Required		Consumed
			Maintenance	Growth		Maintenance	Growth	
1	119R	Neg. control	0.39	0.67	0.48	0.04	0.09	0.02
	12R	Urea	0.39	0.68	0.54	0.04	0.09	0.18
	129R	Pos. control	0.43	0.78	0.57	0.04	0.09	0.08
2	127R	Neg. control	0.51	1.03	0.49	0.04	0.10	0.02
	26R	Urea	0.48	0.94	0.54	0.04	0.10	0.19
	103R	Pos. control	0.50	0.98	0.58	0.04	0.10	0.09
3	110R	Neg. control	0.46	0.87	0.49	0.04	0.10	0.02
	143R	Urea	0.44	0.83	0.55	0.04	0.10	0.20
	134R	Pos. control	0.48	0.94	0.58	0.04	0.10	0.09
4	20S	Neg. control	0.45	0.79	0.34	0.04	0.09	0.01
	122S	Urea	0.45	0.84	0.45	0.04	0.10	0.08
	46S	Pos. control	0.44	0.81	0.45	0.04	0.09	0.08
5	135S	Neg. control	0.41	0.71	0.30	0.04	0.09	0.01
	44S	Urea	0.41	0.72	0.39	0.04	0.09	0.07
	21S	Pos. control	0.43	0.80	0.44	0.04	0.09	0.07
6	47S	Neg. control	0.40	0.67	0.43	0.04	0.09	0.01
	126S	Urea	0.43	0.78	0.45	0.04	0.09	0.08
	154S	Pos. control	0.41	0.73	0.44	0.04	0.09	0.08
7	94T	Neg. control	0.36	0.57	0.28	0.04	0.08	0.01
	91T	Urea	0.34	0.50	0.28	0.04	0.07	0.06
	123T	Pos. control	0.38	0.64	0.28	0.04	0.09	0.07
8	102T	Neg. control	0.36	0.58	0.33	0.04	0.08	0.01
	116T	Urea	0.37	0.62	0.33	0.04	0.08	0.07
	99T	Pos. control	0.40	0.70	0.32	0.04	0.09	0.08
9	104T	Neg. control	0.34	0.52	0.30	0.04	0.07	0.00*
	42T	Urea	0.36	0.58	0.29	0.04	0.08	0.05
	119T	Pos. control	0.36	0.57	0.29	0.04	0.08	0.06
10	30T	Neg. control	0.33	0.50	0.27	0.03	0.07	0.00*
	699T	Urea	0.31	0.48	0.26	0.03	0.06	0.05
	112T	Pos. control	0.34	0.53	0.26	0.04	0.07	0.06
11	37T	Urea	0.40	0.69	0.30	0.04	0.09	0.06
	85T	Pos. control	0.39	0.66	0.30	0.04	0.09	0.07

* The ration was not completely free from nitrogen.

TABLE 8.—CHANGES IN "EMPTY" LIVE WEIGHT AND BODY NUTRIENTS, AND GAINS IN WOOL NITROGEN. SHEEP.

Group No.	Animal No.	Ration	Changes in weights			Gain in wool nitrogen, gm.
			Live weight, kg.	Protein (N × 6.25), gm.	Fat, kg.	
1	119R	Neg. control	− 7	− 700	− 2.7	45
	12R	Urea	− 5	− 119	− 2.6	64
	129R	Pos. control	− 2	+ 238	− 2.6	61
2	127R	Neg. control	− 7	− 956	+ 0.6	44
	26R	Urea	−10	− 856	− 2.7	86
	103R	Pos. control	− 8	− 56	− 3.0	91
3	110R	Neg. control	− 6	− 856	− 3.5	58
	145R	Urea	− 5	− 569	− 1.6	65
	134R	Pos. control	− 2	+ 219	− 3.9	113
4	20S	Neg. control	− 7	− 625	− 2.4	41
	122S	Urea	− 7	− 781	− 1.7	61
	46S	Pos. control	− 6	− 212	− 3.3	65
5	135S	Neg. control	−10	−1419	− 1.7	37
	44S	Urea	− 3	− 225	− 0.5	49
	21S	Pos. control	− 5	− 306	− 1.3	87
6	47S	Neg. control	− 5	−1069	− 3.2	40
	126S	Urea	− 5	− 469	− 2.3	80
	154S	Pos. control	− 5	− 250	− 3.6	106
7	94T	Neg. control	− 1	+ 262	− 3.3	26
	91T	Urea	0	− 44	− 3.1	22
	123T	Pos. control	+ 4	+ 506	− 1.6	57
8	102T	Neg. control	− 3	− 550	− 3.4	22
	116T	Urea	0	− 6	− 3.7	60
	99T	Pos. control	+ 5	+ 525	− 3.1	80
9	104T	Neg. control	− 4	− 675	− 2.7	25
	42T	Urea	− 2	− 306	− 2.4	33
	119T	Pos. control	− 2	− 338	− 2.9	25
10	30T	Neg. control	− 2	− 800	− 1.1	23
	699T	Urea	− 3	− 781	− 1.6	27
	112T	Pos. control	+ 2	− 362	− 1.3	35
11	37T	Urea	− 2	− 400	− 4.2	44
	85T	Pos. control	+ 2	+ 156	− 3.9	38

and final weights. As far as the T.D.N. were concerned the amount consumed was approximately the same as the maintenance requirements and much less than the growth requirements. In five groups the negative controls consumed somewhat less than the others. In regard to the digestible protein the negative control consumed amounts which were less than half the maintenance requirements. This was according to plan. In the first three groups, urea was added at such a rate that the nitrogen was twice that given in the casein. In the remaining groups they were fed

on an equivalent digestible nitrogen basis. The nitrogen consumed from the urea and casein rations approached the requirements for growing and fattening sheep.

In Table 8 are given the amounts of nitrogen put down in the wool, and the changes in live weights, body protein and body fat. The casein ration produced more nitrogen in the wool than the urea ration. The latter, in turn, produced more than the negative controls. These differences, when considered as paired values, were statistically significant.

SUMMARY AND CONCLUSION

1. The value of urea as a source of protein for ruminants was investigated by means of feeding and slaughter trials with 30 head of beef calves and 60 lambs.

2. The animals were divided into groups of five each, two of which were killed and analysed at the commencement of the feeding trial and the remaining three killed and analysed at the end of the trial.

3. Of the three remaining animals in each group, one received a nitrogen-poor basal ration, one received the same ration with urea and one received the same ration with casein equal in digestible nitrogen content to the urea, with sufficient starch or oil removed to equalize the T.D.N. content.

4. The weights and compositions of the three animals in each group at the end of the trial were compared with the initial weights and the initial compositions estimated from the two slaughtered animals.

5. In the case of the beef calves, the animals receiving the nitrogen-poor ration, while maintaining good health and appetite, made small live weight gains, showed practically no deposition of protein or ash but did show some increase in fat.

6. The beef calves receiving the urea ration made relatively good gains in live weight and body nutrients.

7. The beef calves receiving the casein rations made appreciably greater gains in live weight, body protein and ash than those receiving the urea. The gains in body fat were of a similar order for both rations.

8. The gains in total weights of the carcasses, and the gains in weights of protein, ash and water in these carcasses, were greater for the beef calves receiving casein than for those receiving urea. There was little difference between the gains in fat in the carcass with these two rations.

9. The beef calves receiving the nitrogen-poor ration showed some gains in carcass weight and carcass fat with negligible gains in carcass protein and water.

10. As far as chemical composition of carcass gains was concerned those from the beef calves receiving casein tended to be higher in protein, ash and water and lower in fat than those from the animals receiving urea.

11. With the sheep, the casein ration produced more wool nitrogen than the urea and the latter more than the nitrogen-poor ration.

12. Due to the failure of the sheep to consume much in excess of their maintenance requirements for T.D.N., satisfactory conclusions of the value of urea for meat production could not be drawn. The casein rations maintained the body protein against losses to a greater degree than the urea ration and the latter to a greater degree than the nitrogen-poor ration.

13. It was concluded that under the conditions of these experiments and with the rations employed, urea acted as a substitute for feed protein. Its value was less than that of casein.

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THE NUTRITIVE VALUE OF NITROGENOUS COMPOUNDS FOR RUMINANTS

II. THE FORMATION OF BODY PROTEIN FROM UREA LABELLED WITH THE ISOTOPE N^{15}.[1]

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In the first paper of this series (8) it was shown by means of carcass analyses that animals receiving urea deposited more protein than animals receiving the basal ration. In both cases the basal ration was nitrogen-poor. It was not entirely free from nitrogen. There were three possible explanations for the increased protein deposition. The nitrogen of the urea could have been actually used to form protein through the agencies of the microflora of the paunch. The presence of urea may have increased the activity of the microflora to the extent that they would have a greater dissolution action on the fibre of roughages. This could result in the release of more nitrogen for the animal body. Finally, nitrogen of urea may have been used by the microflora as a source of nitrogen in place of the feed nitrogen.

To investigate this point, urea labelled with N^{15} was fed to sheep over a 4-day period. The animals were killed. A sample of oxalated blood was taken. The liver and kidneys were removed and frozen with dry ice. The blood was centrifuged and the plasma used for nitrogen determinations. Trichloracetic acid was used to precipitate the proteins in the plasma and to separate the proteins from the non-proteins in the liver and kidneys. The N^{15} was determined in the non-protein and protein fractions. It was found that in the blood, the kidneys and the livers the protein contained N^{15} in excess of that which would be normally present in the animal body. This fact, combined with the results of the previous paper (8), is considered to be evidence that the nitrogen of the urea is utilized by ruminants to form body proteins.

The principles of the methods of separation and analyses were based on the papers of R. Schoenheimer, G. L. Foster, D. Rittenberg and S. Ratner (4), R. Schoenheimer and D. Rittenberg (7), D. Rittenberg, A. S. Keston, F. Rosebury and R. Schoenheimer (3), A. S. Keston, D. Rittenberg and R. Schoenheimer (1), R. Schoenheimer, S. Ratner and D. Rittenberg (5) and R. Schoenheimer, S. Ratner and D. Rittenberg (6).

EXPERIMENTAL

1. *Preparation of urea containing N^{15}.* The method of preparation is given in the third paper of the series by Leitch and Davidson (2).

2. *Separation of protein and non-protein nitrogen.* The separation of the protein from non-protein nitrogen was effected by the use of trichloracetic acid. In the case of the blood, 100 ml. of 6 per cent trichloracetic were added to 10 ml. of plasma. It was allowed to stand for several hours, decanted on to a filter paper and the procedure repeated twice more. The precipitate was then transferred completely and thoroughly washed. In

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TABLE 1.—N^{15} CONCENTRATION OF TISSUES OF SHEEP RECEIVING NORMAL UREA

Sheep No.	Fraction	N^{15} concentration* (atom per cent excess)
18B	Liver protein N	− 0.040
	Liver NPN	− 0.043
	Blood plasma protein N	+ 0.002
	Blood plasma ammoniacal + urea N	− 0.006
	Urine ammoniacal + urea N	+ 0.016
51B	Liver, protein N	+ 0.011
	Blood plasma protein N	− 0.001
	Kidney protein nitrogen	+ 0.006
	Sample of normal urea	+ 0.003

* Normal abundance of Washington air 0.363 atom per cent.

TABLE 2.—N^{15} CONCENTRATION OF TISSUES OF SHEEP RECEIVING UREA LABELLED WITH N^{15}

Sheep No.	Fraction	N^{15} concentration* (atom per cent excess)
88B	Liver protein N	5.141
	Liver NPN	0.861
	Urine ammoniacal + urea N	2.722
	Urine ammoniacal + urea N	2.429
	Urine ammoniacal N	− 0.005
	Urine ammoniacal N	+ 0.826
29B	Liver protein N	0.502
	Liver NPN	1.314
	Blood plasma protein N	0.153
	Blood plasma NPN	1 872
	Blood plasma ammoniacal + urea N	4.787
	Kidney protein N	0.314
	Kidney NPN	0.658
86B	Liver protein N	0.296
	Liver protein N	0.307
	Liver NPN	0.867
	Blood plasma protein N	0.074
	Blood plasma NPN	1.347
	Kidney protein N	0.232
	Kidney protein N	0.236
	Kidney NPN	1.650
	Sample of urea labelled with N^{15}	31.767

* Normal abundance of Washington air 0.368 atom per cent.

the case of the frozen liver and kidneys 10 gram samples were triturated in an iron mortar with 100 ml. of 6 per cent trichloracetic acid. The material was ground to a homogenous pulp. It was then transferred to a beaker and the procedure mentioned above for blood carried out.

3. *Method of Determination of N^{15}*. The various materials were digested by the Kjeldahl procedure for approximately 12 hours using mercury as a catalyst. After the ammonia had been liberated from an

aliquot in a micro Kjeldahl distillation apparatus, the nitrogen in the resulting ammonium chloride was liberated with alkaline hypobromite according to the method of Rittenberg *et al* (3). The apparatus used was the same as Rittenberg's with a few modifications. The N^{15} concentrations in the resulting samples of nitrogen gas were determined with the mass spectrometer by the Bureau of Standards, Washington.

4. *Rations and animals.* The animals used were Leicester-Shropshire sheep weighing approximately 35-40 Kg. The basal ration consisted of:

Straw	50
Starch	100
Corn oil	20
Oats	100
Hay	600

The animals were fed as much as they could consume but for each pair the consumption was equalized. Vitamins and minerals were fed. Three pairs of animals were used, numbered Groups A, B and C. Within each pair, one animal received normal urea and one received urea containing approximately 30 atom per cent N^{15}. The groups received in 4 days approximately 10 to 12 grams of urea or isotopic urea. This was given mixed with calcium sulphate as a filler in six gelatin capsules daily. The administration was at 4:00 in the afternoon and 9:00 in the morning just following the feeding of the basal ration. On the last day the animals were killed at 1:00 o'clock and the samples of blood, liver and kidneys analysed as described above.

5. *Results.* In Table 1 are given the N^{15} concentrations of various fractions of the animal receiving normal urea. In Table 2 are given the N^{15} concentrations for the animals receiving urea labelled with isotopic nitrogen. These are expressed in terms of atom per cent excess above normal abundance. It is quite evident from these tables that the N^{15} of the urea has been incorporated into the body proteins.

TABLE 3.—N^{15} CONCENTRATION OF PROTEIN NITROGEN AND NON-PROTEIN NITROGEN FRACTIONS OF LIVER TO WHICH N^{15} WAS ADDED

Sample No.	Substance added	Fraction	N^{15} atom per cent excess†
29	$N^*H_4NO_3$	Protein N	− 0.001
30	$N^*H_4NO_3$	Protein N	+ 0.024
9	$N^*H_4NO_3$	Protein N	+ 0.007
10	$N^*H_4NO_3$	Protein N	+ 0.011
11	Urea*	Protein N	+ 0.079
12	Urea*	Protein N	+ 0.024
32	$N^*H_4NO_3$	NPN	7.920
33	$N^*H_4NO_3$	NPN	15.594
34	$N^*H_4NO_3$	NPN	23.388
1	$N^*H_4NO_3$	NPN	14.659
2	$N^*H_4NO_3$	NPN	15.938
3	$N^*H_4NO_3$	NPN	13.385
4	$N^*H_4NO_3$	NPN	3.690
5	Urea*	NPN	7 015
6	Urea*	NPN	7.153

N* Containing approximately 30 atom per cent excess N^{15}.

† Normal abundance of N^{15} in Washington air 0.363, 0.369 and 0.370 according to date of determination.

6. *Testing method of separation.* In the interpretation of results of this type of work the question arises as to whether or not trichloracetic extraction effects a complete separation of protein nitrogen from non-protein nitrogen. To check this, samples of liver were ground in a mortar with varying amounts of ammonium nitrate and urea both of which contained N^{15}. In the case of the ammonium nitrate the concentration was approximately 30 atom per cent in the ammonium radical. In the case of urea the concentration was approximately 30 atom per cent. Separations of NPN and protein nitrogen were carried out by the method described above. The results for the N^{15} content of the protein and non-protein fraction are given in Table 3. This shows that trichloracetic acid was an effective agent for separating the non-protein from the protein material.

SUMMARY AND CONCLUSIONS

1. Urea containing approximately 30 atom per cent N^{15} was fed to sheep for 4 days.

2. The proteins separated from the liver, blood and kidneys contained N^{15} in excess of normal abundance.

3. It was concluded that nitrogen from urea was utilized by ruminants for the formation of body proteins.

ACKNOWLEDGMENTS

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THE NUTRITIVE VALUE OF NITROGENOUS COMPOUNDS FOR RUMINANTS

III. SYNTHESIS OF UREA CONTAINING N^{15}

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In the preceding paper of this series (1) the utilization of urea as a substitute for protein nitrogen in the metabolism of ruminants was confirmed with the aid of urea labelled with N^{15}. The purpose of this paper is to describe the synthesis of isotopic urea from ammonium nitrate containing N^{15} in the ammonium group.

The classic synthesis of Wöbler from potassium cyanate and ammonium nitrate was not applicable in this case because it leads to isotopic dilution of the N^{15}. In the commercial synthesis of urea from ammonia and carbon dioxide a large excess of ammonia is required to realize yields of the order of 80 per cent. Hentschel (2) reported the preparation of urea in 70 per cent yields by passing a rapid stream of dry ammonia through liquid diphenyl carbonate. For the present purpose this method has the same disadvantage as the commercial method. Besides, no urea could ever be isolated from the reaction mixture in our experience. Kirkhgof and Astrova (3) obtained 70 per cent yields of urea by heating a mixture of 22 per cent ammonia and diphenyl carbonate for two hours. The method finally chosen was based on that of these authors. Urea was obtained in yields close to 90 per cent by heating the reactants in a sealed tube at 100° C. for four hours. Directions for preparing urea from ammonium nitrate containing the isotope in the ammonium group are given in detail below.

EXPERIMENTAL

Apparatus

The apparatus is shown in the adjoining figure. "A" is a 100 ml. flask with a trap to prevent any material from spattering over into the reaction tube. "C" contains the diphenyl carbonate and water. The constriction at "F" is to allow easy sealing after the ammonia has distilled over. "D" is a manometer.

Materials

Diphenyl carbonate was prepared as directed by Hentschel (*loc. cit.*) from phosgene and phenol. The ammonium nitrate containing 32 atom per cent excess N^{15} was purchased from the Eastman Kodak Company.

Procedure

Twenty-five ml. of 50 per cent potassium hydroxide were placed in the separatory funnel "B". Eight grams of labelled ammonium nitrate were placed in the flask "A". The tube "C" contained 12.0 gm. of diphenyl carbonate and 8 ml. of water. It was then cooled in liquid air and the system was evacuated. With stop-cock "E" closed, alkali was added dropwise at such a rate that foaming into the trap was avoided. The ammonia generated collected in the reaction tube which was sealed off after an hour. There was practically no rise in pressure within the system during this time. The tube was allowed to come to room temperature and

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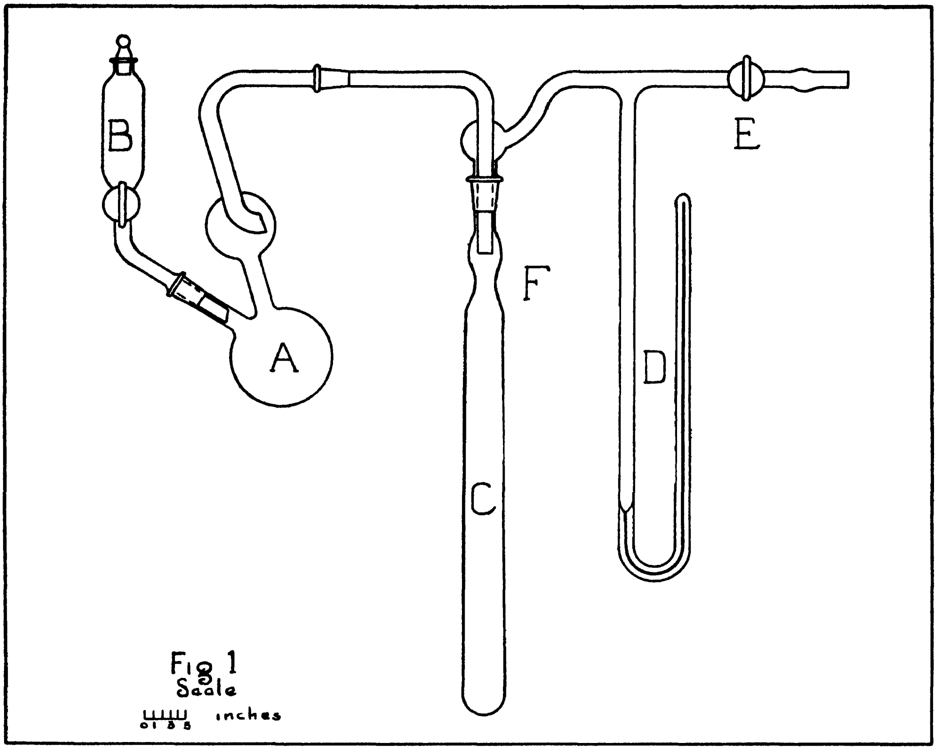

then heated for four hours in a water-bath at 100° C. A small amount of ammonia remaining in the system was absorbed in 10 per cent hydrochloric acid while warming the alkali in the generator.

The reaction products from five such runs were generally worked up together. The combined liquors were diluted to about 200 ml. with water and extracted twice with ether to remove phenol. Crude urea was recovered by evaporating the aqueous solution in vacuo and purified by recrystallization from absolute ethanol using carbon black. The total yield of urea, m.p. 131-3° C., from two crops was 13.0 gm. (86.6 per cent).

In order to recover N^{15} from the mother liquor it was evaporated to dryness in a Kjeldahl flask. The residue was digested with 15 ml. of concentrated sulphuric acid and a trace of copper sulphate. The ammonia liberated by adding 60 ml. of 50 per cent sodium hydroxide to the acid solution (previously diluted to about 150 ml. with water and then cooled) was distilled into the hydrochloric acid used earlier to recover ammonia in the generator. On evaporation to dryness 3.0 gm. of ammonium chloride were obtained. The yield after allowing for recovered ammonium chloride was nearly quantitative.

The synthesis of isotopic urea was also recently reported by Cavalieri, Blair and Brown (4).

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DINITROPHENOL DERIVATIVES AS SUMMER ACARICIDES IN BRITISH COLUMBIA[1]

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The insecticidal properties of dinitrophenol and a number of its derivatives have been known for many years but it was not until 1936 that their value as acaricides was recognized. That year Boyce and Prendergast (2) reported that 2,4-dinitro-o-cyclohexylphenol was highly toxic to the citrus red mite, *Paratetranychus citri* McG. Later, Boyce *et al.* (3, 4, 5) investigated dinitro-o-cyclohexylphenol with and without oil, and its sodium, nicotine, ammonium and triethanolamine salts. They concluded that the citrus red mite, the six-spotted mite, *Tetranychus sexmaculatus* Riley, the common red spider, *T. telarius* (L.) (sic) and the brown clover or almond mite, *Bryobia praetiosa* Koch could be satisfactorily controlled by a one per cent dust of dinitro-o-cyclohexylphenol. Morrison and Mote (10) and Simpson (11) reported excellent control of the common red spider on hops by the same compound at concentrations as low as 0.031 per cent and 0.025 per cent, respectively. Greenslade & Goscombe (7) obtained fair results against the European red mite, *Paratetranychus pilosus* (C. & F.), with one per cent dust of dinitro-o-cyclohexylphenol.

The dicyclohexylamine salt of 2,4-dinitro-o-cyclohexylphenol was first examined as an acaricide by Kagy and McCall (9) who found that, although its toxic action was slower on the citrus red mite than that of the parent compound, it was more persistent. They claimed that the salt was less phytotoxic than the parent compound and that a dust containing approximately 1.7 per cent of the salt was very toxic to the common red spider, the six-spotted mite, the European red mite, the clover mite and the Pacific mite, *Tetranychus pacificus* (McG.). Subsequently, *DN-111*, which is a commercial formulation containing 20 per cent of the dicyclohexylamine salt of dinitro-o-cyclohexylphenol, came into common use as a summer spray. Hough (8) compared several materials for European red mite and apple mite (*Tetranychus schoenei* McG.) control in DDT-sprayed plots. These included *DN-111* at the rate of 1.25 pounds and *DN-Dry Mix No. 1* (40 per cent dinitro-o-cyclohexylphenol) at 0.67 pound per 100 gallons. The latter gave best results. The same substance used at 6 ounces per 100 gallons as a summer spray gave good results according to Cutright and Sutton (6).

EXPERIMENTAL RESULTS

In British Columbia orchards the mite problem has become increasingly troublesome during the last ten years. As early as 1938 growers reported lack of control by materials which previously had appeared quite satisfactory. In 1939 the Dominion Entomological Laboratory, Summerland, initiated experiments with dinitrophenol derivatives for control of European red mite and Pacific mite. The first trials with these compounds

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included both dormant and summer applications of oil solutions of 3,5-dinitro-o-cresol and 2,4-dinitro-o-cyclohexylphenol for European red mite control. The addition of dinitro-o-cresol either to dormant oil or to summer oil in an amount tolerated by apple trees did not seem to improve control. Dinitro-o-cyclohexylphenol, on the other hand, appeared fairly effective in summer oil solution but caused a peculiar browning of leaf petioles and veins. In 1940 the same compounds in oil solution were tested as delayed dormant treatments for Pacific mite and proved to be unsatisfactory.

Summer experiments with the dicyclohexylamine salt of dinitro-o-cyclohexylphenol were undertaken in 1942. Two years' work with a dust (*DN-8*) containing 1.2 per cent of the salt and 1.8 per cent low viscosity oil led to the conclusion that it considerably reduced European red mite and Pacific mite populations but was probably less effective than either one per cent light to medium summer oil or a commercial derris-pine oil-petroleum spray.

With the introduction of DDT for codling moth control the mite problem was further intensified. Among other acaricides, one of the first commercial dinitrophenol derivatives to be examined was *DN-111*. In 1944, this product was used at the rate of one pound per 100 Imperial gallons of spray mixture in five cover sprays against the European red mite. The last spray was applied August 2 and records of the mite population at the end of the season, 34 days later, are summarized in Table 1.

TABLE 1.—EFFECT OF FIVE COVER SPRAYS OF DN-111, 1 LB. : 100 GAL. UPON THE POPULATION OF EUROPEAN RED MITES IN APPLE ORCHARDS (SEPT. 5-6, 1944)

Plot	Materials per 100 Imperial gallons		Average mites per leaf
A	Cryolite*	4 lb.	30.1
	Casein	0.5 oz.	
	Hydrated lime	4 oz.	
	DN-111	1 lb.	
B	Cryolite	4 lb.	25.7
	Casein	0.5 oz.	
	Hydrated lime	4 oz.	
C	DDT tech.	0.5 lb.	24.8
	Acetone	1 qt.	
	Sodium lauryl sulphate†	2 oz.	
	DN-111	1 lb.	
D	DDT tech.	0.5 lb.	59.5
	Acetone	1 qt.	
	Sodium lauryl sulphate	2 oz.	

* Alorco.
† Duponol W. A. Paste.

The addition of the dicyclohexylamine salt of dinitro-o-cyclohexylphenol 0.2 pound per 100 Imperial gallons in five cover sprays failed to reduce populations of the European red mite to a satisfactory level. Further, hydrated lime apparently lessened the effectiveness of the compound which, incidentally caused neither foliage nor fruit injury. The

following year *DN-111* was used with DDT or cryolite at 1.5 pound per 100 Imperial gallons in four cover sprays. Mite damage was assessed by a general inspection of the trees. There was little evident effect on abundance of European red mite but apparently good control of Pacific mite; no spray injury occurred. Where lime was used in the spray mixture, once again the effectiveness of the acaricide appeared to be reduced. Since 1945, *DN-111* has been used on a large scale by growers and to some extent in experimental work. In a number of cases results in European red mite control have been disappointing.

Prior to 1945, the Summerland laboratory had prepared the ammonium and monoethanolamine salts of dinitro-o-cyclohexylphenol. These two salts used in field trials as summer acaricides in 1945 and 1946, were compared with a number of other acaricides then in general use or under experiment. The basic formula was 2 ounces of technical dinitro-o-cyclohexylphenol and one ounce of either 28 per cent ammonia or technical monoethanolamine. Both salts gave satisfactory control of European red mite and Pacific mite. More detailed information of their effectiveness was obtained from hand sprayer (bucket pump) experiments in 1946. In these trials three gallons of each spray mixture were applied to branches of McIntosh apple trees heavily infested with European red mite. No spreading agent was added to the spray materials. Counts of living mites were made microscopically approximately one week after the spray date; egg mortality was not recorded. In Table 2 are given results adjusted according to Abbott's formula (1).

TABLE 2.—EFFECT OF HAND SPRAYER APPLICATIONS OF ACARICIDES UPON EUROPEAN RED MITES INFESTING McINTOSH APPLE TREES (1946)

Materials per 100 Imperial gal.		Mites examined	Per cent living mites	Per cent control
Dinitro-o-cyclohexylphenol Monoethanolamine	2 oz. 1 oz.	1438	0.4	99.2
Dinitro-o-cyclohexylphenol Monoethanolamine	1 oz. 0 5 oz.	1277	12.5	84.0
Di-para-chlorophenylmethyl carbinol (25%)	2 lb.	536	0 9	98.9
	0 5 lb.			
	Trial A	840	1 7	97.4
	Trial B	432	7 2	92.0
DDT (16%) hydroxypentamethyl flavan (20%)*	5 0 lb. 2 5 lb	1410 1008	1 2 3 3	97.7 93.9
Dinitro-o-cyclohexylphenol 2 oz. Ammonia (28%) 1 oz.	Trial A Trial B	1139 770	4.0 13.5	94.8 84.8
Dicyclohexylamine dinitro-o-cyclohexylphenolate (20%)	1 lb. 0 5 lb.	987 955	5 6 24.0	91.2 62.3
Disodium ethylene bis dithiocarbamate**	2.0 lb. 0.5 lb.	576 663	49.3 59.6	44.6 33.0
DDT (25%), mixture alkyl naphthyl ethers (72%)†	2.0 lb. 0.5 lb.	789 656	65.4 80.6	26.5 9.4

* DDT Miticidal.
** Dithane D-14.
† Syndeet.

TABLE 3.—EFFECT UPON EUROPEAN RED MITES OF ACARICIDES INCLUDED IN THE FIRST FOUR COVER SPRAYS OF 50 PER CENT DDT 1 LB. : 100 GAL. AVERAGE NUMBER MITES PER LEAF*

Plot	Materials per 100 Imperial gallons	May 26	June 3	June 10	June 18	June 30	July 8	July 16	July 29	Aug. 11	Aug. 20	Sept. 11	Season average
A	Check Plot Cryolite **, 4 lb. Summer oil†, 0.25 gal. (1st and 5th covers), 0.5 gal. (2nd, 3rd and 4th covers)	0.9	5.0	8.1	1.6	—	19.4	42.7	15.8	13.9	5.4	1.6	11.4
B	Dinitro-o-cyclohexylphenol, 2 oz. Monoethanolamine, 1 oz.	0.1	0.2	0.3	0.2	—	6.1	14.8	12.4	22.0	8.9	2.9	6.8
C	Dinitro-o-cresol, 2 oz. Monoethanolamine, 1 oz.	1.1	19.1	17.5	7.9	75.6				Discontinued			
D	Dinitro-o-cresol (50%), 4 oz.	0.5	18.1	21.7	24.5	130.8				Discontinued			
E	Check Plot (same as Plot A)	0.4	1.5	2.3	0.9	—	8.0	44.1	13.2	12.2	1.9	3.3	8.8
F	Dicyclohexylamine dinitro-o-cyclohexylphenolate (20%), 0.5 lb.	0.6	7.8	7.2	7.9	—	48.9	59.6	39.5	11.5	10.8	1.1	19.5

* Vertical lines indicate spray treatments.
** Kryocide.
† Shell Helix 15.

In these trials no spray injury occurred. Control of European red mite by monoethanolamine dinitro-o-cyclohexylphenolate was apparently excellent; the ammonium salt seemed slightly less effective.

In 1947, fairly extensive experiments were undertaken with 20 acaricides in a number of combinations and dilutions. These included such dinitrophenol derivatives as 3,5-dinitro-o-cresol, 2,4-dinitro-o-cyclohexylphenol and 2,4-dinitro-6-secondary butyl phenol. In one series of experiments some of these compounds and their monoethanolamine and dicyclohexylamine salts were applied throughout the season for European red mite control in combination with DDT codling moth sprays; cryolite-oil was used throughout the season on the several check plots. A full spray program consisted of five codling moth sprays applied May 17, May 27, June 13, July 23 and August 13 by a stationary high pressure sprayer. The acaricide was included in the first four sprays but, as will be noted in Table 3, in two instances the mite populations rose to such high levels that the acaricides then in use had to be discontinued in favour of more toxic materials. Each plot consisted of 5 to 8 Delicious apple trees of which five trees were sampled for mites by the Venable's technique (12) before spraying (except before first cover) and again three or more days after spraying. Results are shown in Table 3.

In the same experimental block single applications of a number of acaricides were made at various times in June and July. Results from the dinitrophenol derivatives and their monoethanolamine salts are shown in Table 4.

TABLE 4.—COMPARISON OF MITICIDES IN SINGLE APPLICATIONS. AVERAGE NUMBER EUROPEAN RED MITES PER LEAF

Trial	Materials per 100 Imperial gal.	Spray date	Before spray	Days after spray					
				4	5	6	7	13	19
1	DDT (50%)*, 1 lb 2,4-dinitro-6-sec. butyl phenol. 1 oz. Monoethanolamine, 0.5 oz.	June 11	26.6	—		—	2.5	—	42.1
2	Same as Trial 1 but DDT omitted	June 30	42.1	2.2	—	–	—	7.9	—
3	DDT (50%), 1 lb. Dinitro-o-cyclohexylphenol (40%), 5 oz.	July 23	57 2	—	–	17.3	—	—	39.4
4	DDT (50%), 1 lb. Polyethylene polysulphide†, 1 pt. Dinitro-o-cyclohexylphenol, 1 oz. Monoethanolamine, 0 5 oz.	June 17	17.6	—	—	23 3	—	76.2	—
5	Dinitro-o-cyclohexylphenol, 1 oz Monoethanolamine, 0.5 oz.	July 3	76.2	—	26 8	—	—	37.5	—

* Penco-WB-50.
† Good-Rite P.E.P.S.

On another block of McIntosh and Delicious apple trees, 40 per cent dinitro-o-cyclohexylphenol and the monoethanolamine salt of the technical compound were compared with Parathion and several other acaricides for

European red mite control. The materials were applied July 10 and July 14 without a spreading or wetting agent to plots consisting of 18 to 25 trees. Fifty per cent of these were sampled for mites immediately before spraying and 4 days, 15 to 19 days and 30 to 34 days after spraying. Results from the three materials are shown in Table 5.

TABLE 5.—COMPARISON OF 40 PER CENT DINITRO-O-CYCLOHEXYLPHENOL, THE MONOETHANOLAMINE SALT OF DINITRO-O-CYCLOHEXYLPHENOL AND PARATHION. AVERAGE NUMBER EUROPEAN RED MITE PER LEAF

Plot	Materials per 100 Imperial gallons	Before spray	4 days after	15-19 days after	30-34 days after
A	Dinitro-o-cyclohexylphenol 2 oz. Monoethanolamine 1 oz.	30 7	3.2	11.9	33.3
B	Dinitro-o-cyclohexylphenol (40%) 5 oz.	27.2	6.5	36.6	30.6
C	Parathion (15%)* 0.5 lb.	58.3	0.2	3.6	24.7

* Thiophos-3422.

DISCUSSION

Of the dinitrophenol derivatives most extensively examined for European red mite control in the Okanagan Valley of British Columbia, the monoethanolamine salt of 2,4-dinitro-o-cyclohexylphenol has been the most effective in respect of its initial kill and in its residual action. When used with DDT as a summer application at the rate of 2 ounces of the parent compound per 100 Imperial gallons of spray mixture this salt gave reasonably satisfactory control of European red mite both in experimental work and in the hands of many fruit-growers. At 1 ounce per 100 Imperial gallons it was not sufficiently toxic. In addition to the dinitrophenol derivatives mentioned in the tables (dinitro-o-cyclohexylphenol, monoethanolamine dinitro-o-cyclohexylphenolate, ammonium dinitro-o-cyclohexylphenolate, dicyclohexylamine dinitro-o-cyclohexylphenolate, dinitro-o-cresol, monoethanolamine dinitro-o-cresolate, and monoethanolamine dinitro-o-secondary butyl phenolate) the following acaricides were applied in field trials: summer oil, xanthone, hexaethyltetraphosphate, chlorinated camphene, hydroxypentamethylflavan, disodium ethylene bis bithiocarbamate, alkyl naphthyl ethers, rotenone-summer oil, water-soluble tobacco compounds. None of these was as satisfactory as monoethanolamine dinitro-o-cyclohexylphenolate. Dinitro-cyclohexylphenol used alone as "*DN-Dry Mix No. 1*" was apparently not quite as toxic to European red mite as its monoethanolamine salt.

Neither 3,5-dinitro-o-cresol nor its monoethanolamine salt had appreciable acaricidal value as summer sprays at feasible concentration. On the other hand, the monoethanolamine salt of 2,4-dinitro-6-secondary butyl phenol was promising when used at the rate of one ounce of the parent compound per 100 Imperial gallons of spray mixture. At double this concentration it may prove superior to an equal amount of the same salt of dinitro-o-cyclohexylphenol.

Among the acaricides employed simultaneously with DDT in four cover sprays in the experimental orchard the dicyclohexylamine salt of dinitro-o-cyclohexylphenol resulted in the heaviest European red mite damage. Used as the commercial formulation *DN-111*, at 0.5 pound per 100 Imperial gallons, that is, 1.6 ounces of the parent compound, it failed to give adequate control of European red mite. In fact, mite populations remained static after the first spray and quickly increased after two others. In grower trials under laboratory supervision from 0.75 pound to one pound of *DN-111* was added to a 50 per cent wettable DDT mixture in three or more cover sprays. The poor control of European red mite that followed suggests that this DDT formulation actually reduced the acaricidal value of the dicyclohexylamine salt. Cutright and Sutton (6) found that certain dinitrophenol derivatives in combination with DDT acted erratically in their performance against mites and in some instances caused fruit and foliage injury. Generally speaking, at least one pound of *DN-111* per 100 Imperial gallons has been necessary for European red mite control in British Columbia, and even then results have not been uniformly satisfactory. It is suspected that the type of the extender used with DDT may have some bearing on the matter.

On apples dinitro-o-cyclohexylphenol and its monoethanolamine salt have been used rather widely at effective dosages with little evidence of phytotoxicity under British Columbia conditions. In early cover sprays both materials on occasion have produced slight marginal burning of terminal leaves of water shoots. Although it is well known that the dinitrophenol derivatives in question cannot be applied to apple or pear foliage with impunity, there have been, in the Okanagan Valley, some surprising results from errors in concentration. The current summer strength recommendation for *DN-Dry Mix No. 1*, for example, is five ounces per 100 Imperial gallons; nevertheless, growers have used from one pound to even five pounds per 100 gallons without sign of foliage or fruit injury. Doubtless they were favoured by unusually cool weather since high temperatures appear to be conducive to damage from these preparations.

Pear foliage and fruits, particularly of the Anjou variety, seem to be more susceptible to injury from dinitrophenol derivatives than do apple foliage or fruits. In 1947 severe blackening of foliage on Anjou trees and pronounced lenticel injury on the fruit followed the application of a second cover spray of 50 per cent wettable DDT together with either the monoethanolamine salt or the dicyclohexylamine salt of dinitro-o-cyclohexylphenol. Bartlett pears were not so severely affected. Foliage injury was of no particular concern but fruit damage was still of commercial importance. During spraying and for two days thereafter maximum temperatures were 90°F., 90° F., and 83° F., and relative humidities were 27 per cent, 31 per cent and 41 per cent, respectively. It is presumed that unseasonably hot weather, coupled with the exceptional tenderness of the young pear foliage and fruits, brought about the injury. The use of dinitrophenol derivatives on pears is not recommended in the interior of British Columbia prior to the third cover spray.

It is interesting to note that the use of the monoethanolamine salt of dinitro-o-cylohexylphenol has resulted—at least in some cases—in increased size of fruit. According to packing-house officials, apples packed from orchards using this material were of exceptional size. That their impressions were probably correct is indicated by field experiments conducted by the Summerland Laboratory during 1941, 1942 and 1943. These experiments showed that fruits from McIntosh apple trees sprayed with sodium or ammonium dinitro-o-cresolate at the rate of 4 ounces of dinitro-o-cresol per 100 Imperial gallons in 5 codling moth cover sprays were approximately 20 per cent larger than those on adjacent trees that had received no dinitro-o-cresolate. Although instances of increased fruit size following the use of dinitrophenol derivatives may have been due in part to control of mites it seems more probable that it stemmed from chemical stimulation of the trees. It is hoped that this interesting manifestation will shortly be studied by the plant physiologists.

The experiments that have been discussed culminated in the official recommendation of the monoethanolamine salt of dinitro-o-cyclohexylphenol for the summer control of orchard mites in British Columbia during 1948. The recent improvements in acaricides has been so rapid, however, that this material may be supplanted within a year or two by one or more of the newer organic compounds presently under investigation.

SUMMARY

1. Since 1939 a number of dinitrophenol derivatives have been under investigation for orchard mite control in the Okanagan Valley of British Columbia. These derivatives included various formulations of the parent compounds 3, 5-dinitro-o-cresol, 2,4-dinitro-o-cyclohexylphenol and 2,4-dinitro-o-secondary butyl phenol and some of their ammonium, monoethanolamine and dicyclohexylamine salts.

2. The monoethanolamine salt of dinitro-o-cyclohexylphenol at the rate of 2 ounces of the parent compound per 100 Imperial gallons of spray mixture has given most satisfactory mite control, taking effectiveness, cost and availability into consideration. When used with DDT in four codling moth cover sprays this compound gave better control of European red mite than did summer oil, xanthone, hexaethyltetraphosphate, chlorinated camphene, hydroxypentamethylflavan, disodium ethylene bis dithiocarbamate, alkyl naphthyl ethers, rotenone-oil and water soluble tobacco compounds.

3. The dicyclohexylamine salt of dinitro-o-cyclohexylphenol failed to give consistent commercial control of European red mite.

4. Dinitro-o-cyclohexylphenol with summer oil was fairly effective as a summer spray against both species of mites but considerable foliage injury followed its application. Used alone as the commercial formulation *DN-Dry Mix No. 1* at 5 ounces per 100 Imperial gallons this compound did not injure orchard foliage but apparently it was not quite as toxic to European red mite as its monoethanolamine salt.

5. Dinitro-o-cresol, with or without oil, at concentrations tolerated by apple trees was ineffective against both European red mite and Pacific mite, as also was its monoethanolamine salt.

ACKNOWLEDGMENTS

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BOOK REVIEW

AN INTRODUCTION TO ORGANIC CHEMISTRY, by Roger J. Williams and Lewis F. Hatch, The University of Texas. Fifth Edition. 668 pp. 1948. D. Van Nostrand Company, Inc., Toronto. $6.50.

This textbook has been thoroughly revised and material included to keep pace with developments in the field of organic chemistry. The subject matter has been arranged in a logical manner with proper emphasis on industrial, medical and agricultural applications. The problems at the conclusion of each chapter assist the student in assessing his grasp of the subject and the inclusion in the text of biographical sketches of outstanding chemists adds interest to the book. Considerable care has been exercised in the selection of compounds to be represented by structural formulae. A sufficient number has been included to illustrate the many classes encountered in organic chemistry yet simplicity has not been sacrificed.

A complete index gives the book value as a reference as well as a text. Workers in agriculture might profitably consult it in order to gain a general picture of their problem before resorting to specialized material.

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THE EFFECTS OF TEMPERATURE AND MOISTURE UPON THE BEHAVIOUR OF THE SPRUCE BUDWORM, *CHORISTONEURA FUMIFERANA* CLEMENS (LEPIDOPTERA: TORTRICIDAE)

I. THE RELATIVE IMPORTANCE OF GRADED TEMPERATURES AND RATES OF EVAPORATION IN PRODUCING AGGREGATIONS OF LARVAE[1]

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[Received for publication September 14, 1948]

INTRODUCTION

This paper is the first of a series dealing with the effects of temperature and rate of evaporation upon the behaviour and activity of the spruce budworm, *Choristoneura fumiferana* (Clemens). Much of the work was concerned with the orientation reactions exhibited by the six larval stages in response to stimulation by these variables. The reactions studied most thoroughly were those which resulted in the aggregation of groups of larvae in what are commonly termed "preferred" zones. Although the studies reported in this and a succeeding paper were carried on simultaneously and are, in some respects, not easily separable, it is necessary, for the present, to distinguish between behaviour in gradients of the combined variables and behaviour in gradients of the single variable, evaporation. Thus, in the following pages, the descriptions of methods and of apparatus will in large part apply to work discussed in the subsequent paper also.

Although the work reported in this series is part of an investigation designed to provide data for the development of a number of different types of studies of the effects of weather and climate upon the spruce budworm, in the present paper the animal has been used to demonstrate an academic point.

Rate of evaporation, despite objections stemming from the lack of easily comparable units, was used in the present work to demonstrate a relationship which would have been masked by measurements of relative humidity or saturation deficit. This is dealt with at greater length in the discussion, but it is beyond the scope of this paper to extend the controversy on the relative merits of the various methods of expressing atmospheric moisture for biological purposes. Those who may prefer the earlier arguments of Mellanby (8) and Anderson (1) are referred to the papers of Ramsay (9), Leighly (7) and Thornthwaite (13).

[1] Contribution No. 2568 from the Division of Entomology, Science Service, Dominion Department of Agriculture.
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EXPERIMENTAL MATERIAL

Unless otherwise noted, the insects used in the experiments were collected near Lake Nipigon, Ontario, during October, 1945. Branches of balsam fir infested with overwintering larvae were stored first under snow cover in a screened insectary, and, later, before the spring thaw in March, 1946, were transferred to a cold room held between 2.5 and 4.5° C. Bundles of the foliage were brought from cold storage as required, and emerging larvae were collected with a brush or a pump-driven aspirator and reared at 20-21° C. until reaching the required instars.

APPARATUS

Two types of gradients were used in the experiments. The design of the apparatus to produce the gradients used presented no particular problem, but it was necessary to find some means of measuring the rates of evaporation within them. This instrument will be treated first.

The Evaporimeter

This instrument had to be small enough to be enclosed in the confines of a gradient, yet capable of measuring the rates of evaporation within a gradient rapidly enough so that the slope of the gradient of evaporation could be changed quickly, if desired. Ordinary spherical atmometers were too large for the size of the apparatus used. However, Ramsay, Butler and Sang (10) described a capillary-tube evaporimeter which was used as the basis for the model fashioned for use in this investigation.

In its original form, the instrument of Ramsay *et al.* was roughly comparable to the Piche evaporimeter. However, it was constructed on a much smaller scale. It consisted of a disc of cigarette paper 2 mm. in diameter, which was attached to one end of a capillary tube filled with water. The rate of evaporation was determined by observing the movement of the meniscus along the bore of the tubing. This was done with the aid of a travelling microscope used with the unit.

For the purposes of this investigation, the microscope was discarded, since such an arrangement was too bulky. White-backed thermometer tubing of 0.5 mm. bore was substituted for ordinary capillary tubing. The white tubing gave enough contrast so that the position of the meniscus could be determined from ordinary reading distance. Lens-fronted, red-backed thermometer tubing might have been employed to give an even greater contrast, but it was not available at the time when the instruments were required. Its use is recommended for future patterns.

The millimeter scale was drawn in India ink on the gummed side of a strip of transparent cellulose tape, which was then fixed in position along the bore of the tubing. This type of scale proved to be extremely durable if it was painted over with a thinned solution of cellulose acetate. Filter paper discs 4 mm. in diameter were used in place of cigarette paper, since the only available brand of the latter was not suitable for an evaporative surface. The filter paper used was a loose-textured type (Cenco No. 13255).

The net result was an instrument of pocket-size (Figure 1) which could be placed in spaces of very restricted volumes. Since it lacked an attached microscope, it could not be read instantaneously, but this proved to be

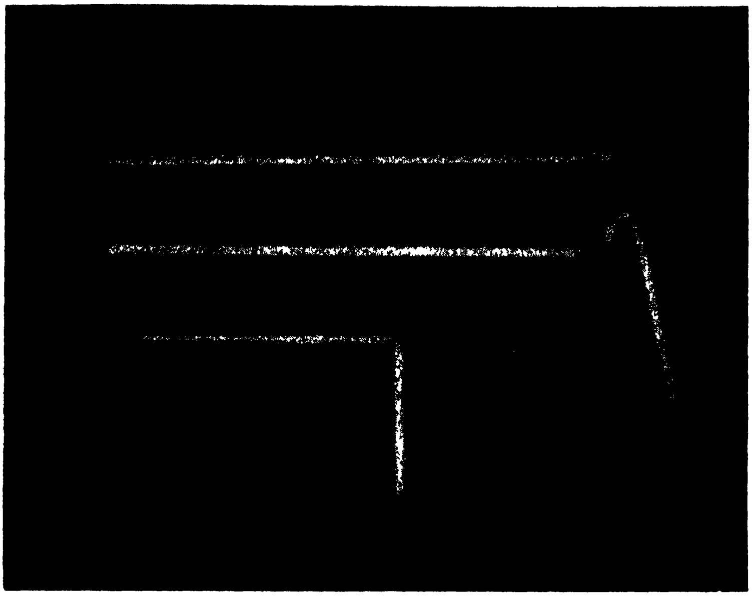

FIGURE 1. Sample types of capillary-tube evaporimeters fashioned from white-backed thermometer tubing. The straight tube at the top was used for measurements reported in this paper. The filter paper disc appears at the lower right of the illustration (disc diameter, 4 mm.).

unimportant during the measurements, for stable conditions commonly existed. The times required for reading the rates of evaporation varied from 2.5 minutes for rapid rates to 10 minutes for very low rates close to actual saturation. Over most of the range, 5 minutes was the interval employed. Since stable conditions existed at any point, readings were converted to cu. mm. per minute.

The Evaporation Gradient Apparatus

For observations on the reactions of larvae to evaporation at a constant temperature, apparatus producing a linear, rather than a concentric gradient was constructed, since available materials did not lend themselves to the construction of the latter type. This apparatus was much the same as that described by Sokolov (11). It consisted of a floorless box of black "Masonite" 45 cm. long, 8 cm. wide and 2.8 cm. high. A glass top was cut to fit and could be sealed with cellulose tape. Another box was constructed to fit snugly within the original box. The second frame was 5 mm. lower than the first, so that, when topped by a platform, it formed the floor of the experimental chamber. Fifty-one mesh nylon was used for the experimental platform. When it was placed loosely over the top of the second box, forcing the outside box down over the whole drew the nylon taut. A line of Syracuse dishes was placed beneath the experimental platform. The dishes contained, in sequence, wet cotton, wet and dry sodium carbonate and wet and dry calcium chloride. Usually only about 35 cm. of the length of the gradient was used, except in certain experiments with light, so that, as a rule, all the dishes were placed within this area. The rest of the gradient was then blocked off so that larvae were confined to the working area.

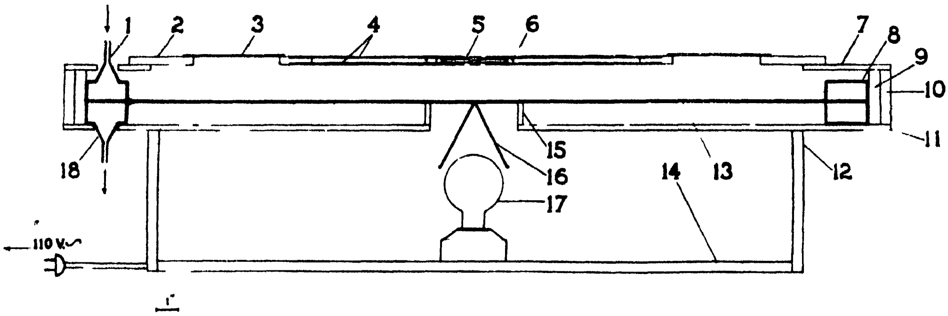

FIGURE 2. Apparatus for producing gradients of temperature and evaporation: Sectional elevation along one diameter. *1*, water inlet; *2*, roof; *3*, port covers, *4*, transparent double roof; *5*, slide; *6*, bracing strip; *7*, supporting frame; *8*, marginal cooling duct; *9*, bracing strip; *10*, supporting frame; *11*, supporting frame; *12*, base; *13*, brass disc forming working surface of gradient; *14*, mounting board for lamp; *15*, bracing strip; *16*, heat-conducting cone; *17*, heating lamp; *18*, water outlet.

The Combined Temperature and Evaporation Gradient Apparatus

Most of the literature describing the various types of apparatus devised to study the temperature preferences of terrestrial animals, with or without provision for the study of the relation of atmospheric moisture to these aggregations, has been summarized by Herter (6), Fraenkel and Gunn (4) and Deal (3), so that it need not be included here. For this investigation, it was decided that a concentric gradient (cf. Totze (14)) would best meet the particular needs. The apparatus devised had some special features which are described below (see also Figure 2).

The working surface of the gradient consisted of a brass disc 3 mm. thick and 90 cm. in diameter. To the centre of the disc, on its lower surface, was soldered a truncated copper cone 7 cm. deep and 7 cm. in basal diameter. This served to conduct heat from the source, a 40-watt lamp, to the centre of the disc, whence it passed to the periphery.

Around the margin of the disc was drilled a row of 1 cm. holes, spaced at 15 cm. intervals. Enclosing these there was a water-tight copper duct, which was soldered to the adjacent surfaces of the disc around its entire margin. This duct was 5 cm. square and 90 cm. in outside diameter. As the duct served as a marginal cooling ring, a water inlet and an outlet were provided, the former on the upper surface of the duct and the latter on the lower surface, 5 cm. along the duct from the position of the inlet. The inner passage immediately between the two was sealed by means of two 2.5 × 5 cm. strips of copper soldered to the inner surfaces of the duct and the enclosed disc, so that the introduced coolant was forced around the entire periphery between the times of its entrance and exit.

The metal work was set in a shallow, square plywood box just deep enough to hold it. The box, together with a square wooden base, served as both support and insulation. The lamp which served as a heat source was mounted on a detachable board on the base to permit replacement of the lamp. In the lid of the box was cut a circle 75 cm. in diameter. Over the hole was placed a detachable roof, consisting of a plywood disc 80 cm. in diameter. On one diameter, two 10 × 12.5 cm. ports were cut through

the roof, each placed 7.5 cm. from the adjacent margin of the disc. The central portion of the roof consisted of two sheets of 3 mm. cellulose acetate separated by a 6 mm. air-space to form a double roof which provided an observational area measuring 37.5 × 75 cm. at its widest point. Two bracing strips separated the sheets near the centre line of the roof. Between the braces, and partially enclosed by the acetate sheets, lay a "Lucite" slide, 0.6 × 6 × 80 cm. Two 2.5 × 37.5 cm. slots were cut through the sheets along the radius above and below this slide, to facilitate introduction of thermocouples or material through two holes drilled near the centre of the slide.

To set the apparatus in operation, the roof was set in place, glass slides were placed over the ports, and the light and the water supply (see below) were turned on. The apparatus was always used in a rearing room held between 20° and 21° C. Under these conditions, a working gradient could be established in 15 minutes, and could be maintained indefinitely.

There was available a water-storage tank which was held at a constant low temperature by means of a "Freon" cooling coil. A line from this was connected to the inlet of the cooling duct of the apparatus. With a rate of flow of 1 litre per minute, it was found that the temperature of the incoming water was held at 7° C., and that the water warmed to 7.5° in its circuit of the duct. Thus, the isotherms on the working surface were not strictly concentric. Nevertheless, they could be considered so for practical purposes, since the half-degree difference between incoming and outgoing water diminished to a peripheral difference of 0.1° when measured on the disc.

The gradient of temperature obtained amounted to 30 Centigrade degrees (40° − 10°) over a radial distance of 40 cm. Although the fall was not regular, no undesirable effects were noted in the work. It was possible to measure the surface temperature at any point with only one searching junction, by setting the "Lucite" slide and rotating the roof until the hole in the slide came to the desired position.

The amount of moisture in the enclosed air was changed by attaching moistened cotton pads or sacks of drying agents to the under surfaces of the opaque plates covering the ports. As long as the roof was kept in one position, the moisture gradient remained concentric except in the immediate vicinity of the pads, where the regularity of the iso-lines was destroyed. The reactions of the insects kept this from becoming a problem in the observational work. A number of stable gradients of evaporation were obtained which could be checked at a few standard points.

A disadvantage of this apparatus stemmed from the fact that it was impossible to obtain suitable materials for its construction during 1945. The roof should have been completely transparent. In the present work, it so happened that accurate observations could still be made, because the behaviour of the larvae eliminated the difficulty. However, the objection still stands if similar apparatus is to be used with other species of different habits.

METHODS

The "bar" evaporation gradient was always used at room temperature, and hence was ready for use at any time. Its stability was checked with the evaporimeter before and after any experiment. The temperature gradient proper was left running day and night. One half-hour before an experiment began, the appropriate evaporation gradient was established in the apparatus. Both the temperature and evaporation gradients in the apparatus were checked at three points along a radius of the disc before an experiment and during the latter half of any one hour's observation, and the values obtained checked against the original calibration curves.

Insects were introduced into either apparatus with a brush. They were distributed evenly along or throughout the working area, with the important exception that, in the temperature gradient, larvae never were dropped above the 36° C. isotherm. It was observed that small larvae dropped into zones of temperature higher than this seemed unable to orientate quickly enough to escape before being injured by the high temperature. On the other hand, if larvae wandered into the upper zone while moving about the disc, they were able to reorientate quickly. Thus, it was thought to be better to let them wander into this zone rather than to drop them into it.

The time at which the last larva of a group was placed in any apparatus was reckoned as zero time for the observation which followed. If instars 1 to 3 were used, it was necessary to check the condition of these larvae after an interval of five minutes, because a few of them were occasionally injured by the brush and became inactive. They were removed and replaced by others of the same instars held in reserve for this purpose. The number of necessary replacements was never more than 3 per cent, and it was considered better to replace injured and sluggish larvae before the actual observations began rather than risk the occurrence of a spurious peak in a final distribution such as would be caused by these larvae remaining at one point.

The first record of the positions of the larvae was made fifteen minutes after the zero of time. The first three instars of the spruce budworm moved about almost incessantly on a bare surface, but, with practice, it was possible to record the positions of 100 larvae, the usual number in a group, in 2.5 minutes.

It was found that four observations in any one hour on 100 larvae were more than sufficient to establish the distribution peculiar to the time interval. The last three observations in any one hour were taken at 30, 45 and 60 minutes, as reckoned from the zero of time.

The positions of the larvae in both types of apparatus were always recorded in terms of distance from a fixed point on the gradients rather than in terms of the units of temperature or evaporation employed. This method of recording positions raised no problem in the narrow evaporation gradient, but in the concentric gradient, concentric rings spaced 6 mm. apart had to be shallowly enscribed in the surface of the brass to provide some means of locating the larvae. These rings were numbered from the centre to the periphery. During each observation, the number of larvae in each ring was recorded, and the results later translated into class intervals

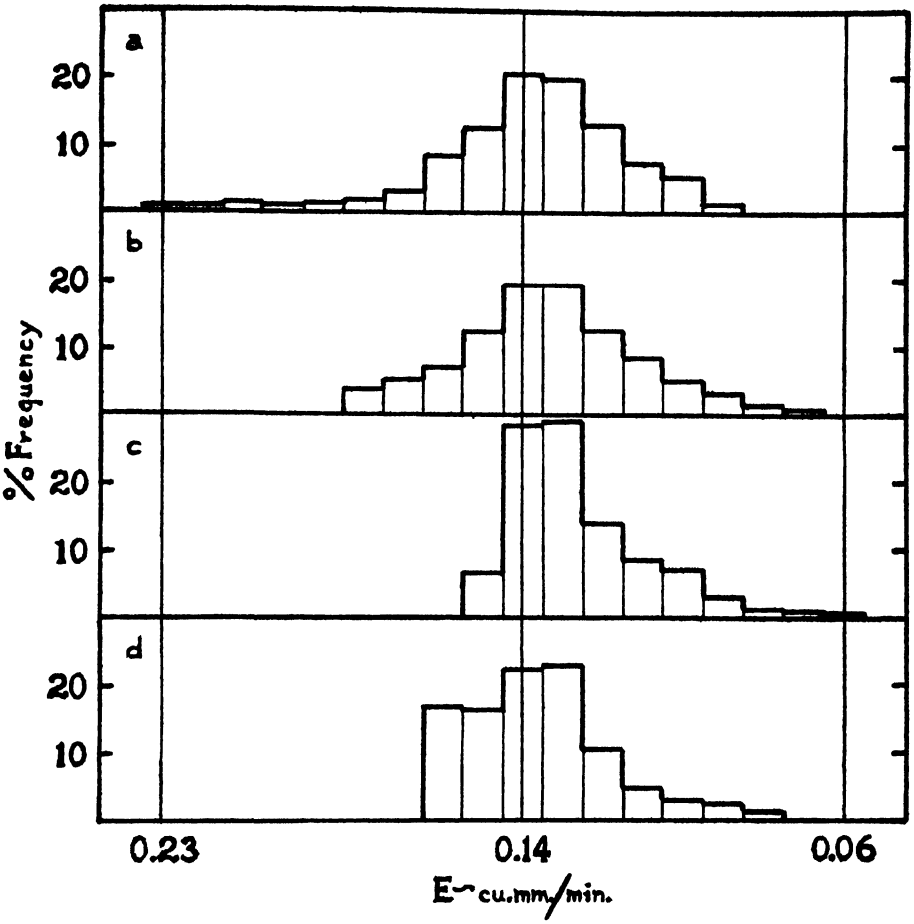

FIGURE 3. Aggregations in response to evaporation exhibited by four groups of initially moist second stage larvae in four types of gradients: *a:* in a dry temperature gradient where the 36° C. isotherm lay above an evaporative rate of 0.23 cu. mm. per min.; *b:* in a moist temperature gradient, with the 36° C. isotherm above 0.18 cu. mm. per min.; *c:* in a very moist temperature gradient, with the 36° C. isotherm above 0.15 cu. mm. per min.; *d:* in a gradient of evaporation which did not extend above 0.16 cu. mm. per min., but which was at a constant temperature of 20.6° C. Ordinate: percentage frequency; abscissa: rate of evaporation, cu. mm. per min.

of evaporation or temperature. No larvae of any instar reacted to the presence of these rings. Furthermore, no larva was ever observed to react to the silk trails of other larvae, but, as a precaution against eventual occurrence of such behaviour, the surfaces of the gradients were always wiped clean after any experiment was completed.

RESULTS

It soon became apparent that the previous treatment of the larvae under observation was of the utmost importance. If this treatment was not kept within rigid limits, inconsistencies developed among the results of observations on supposedly similar groups of larvae.

It was found that, in any one experiment, it was possible to obtain repeatable observations within the first two or three hours of the run, if the larvae had been similarly treated beforehand. Thereafter, the original type of distribution broke down, and bimodality or trimodality appeared. This state persisted for some twelve hours. At times, single peaks were formed which resembled the original type of distribution. In the last six hours of a twenty-four hour period, another stable type of distribution was formed, with the peak considerably lower with respect to both temperature and evaporation than that of the original type of distribution. If the larvae were not given any special treatment in advance, bimodality or the final type of distribution appeared during the first two hours.

It finally became evident that the moisture conditions under which the larvae were stored before testing were the most important conditions involved. (These points will be treated further in a later paper, but some indication is necessary in this presentation.) It was found that, whether larvae were to be dried or kept moist while in storage, the container in which they were placed had to be lined with the desiccating or humidifying agent, so that there was no possibility of larvae resting anywhere but on the surface of the reagent. If this procedure was followed rigidly, bimodality disappeared from the readings of the first two or three hours and consistent results were obtained with a minimum of readings.

The results presented below are based on the reactions of larvae stored in a saturated atmosphere for periods of four or more hours. Larvae of any instar moistened in this way aggregated in the driest zones (maximum rates of evaporation) of any groups tested within an instar. The aggregations at these maximum rates, discussed further in a following paper on responses to evaporation, proved to be very stable within an instar, and hence provided a useful standard for comparative purposes.

The distribution of larvae of any one instar could be plotted against either temperature or evaporation to obtain a satisfactory frequency distribution. Nevertheless, if all the distributions obtained from groups of one instar subjected to several gradients of evaporation in one gradient of temperature were plotted against temperature and compared, each distribution showed a distinctly different "preferred" zone of temperature. On the other hand, when these same distributions were plotted against rate of evaporation, it was seen that the larvae of the instar aggregated in one zone of evaporation, wherever this zone was placed in a wide range of temperature. This held over the range of temperature investigated, to the extent that 10° C., the lowest temperature available, did not limit the evaporation responses, while, for most instars, a temperature of about 36° C. (cf. Wellington (16)) imposed a barrier beyond which most larvae would not follow the rate of evaporation. The above statements are borne out by consideration of data for the second and sixth instars, which represent the two extremes in evaporation responses, and so give wide differences in position with respect to temperature.

If the larvae of the second instar were stored in saturated air for 4 hours or more, they exhibited a distribution with its peak at rates of evaporation of 0.13 to 0.14 cu. mm. per minute. Figure 3 shows the graphic representation of this type of distribution as obtained with four groups of larvae exposed to four different types of evaporation gradients.

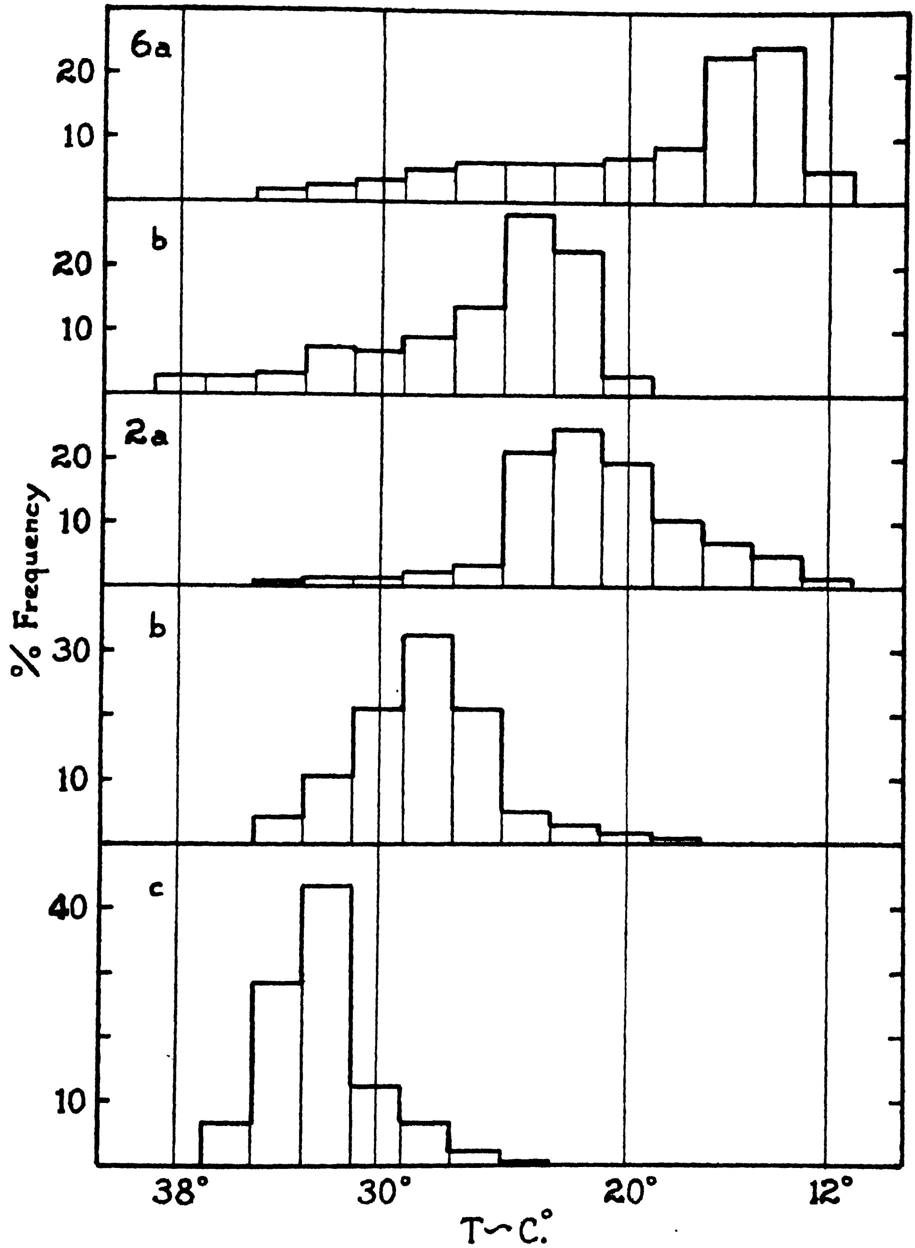

FIGURE 4. Types of distributions obtained when the numbers of larvae observed at different points in the gradients were plotted against temperature instead of evaporation: Instars 2 and 6. Instar 2: *a:* in a dry temperature gradient; *b:* in a moist temperature gradient; *c:* in a very moist temperature gradient (cf. Figure 3, *a* to *c*). Instar 6: *a:* in a moist temperature gradient; *b:* in a very moist temperature gradient (cf. Figure 5, *a* and *b*). Ordinate: percentage frequ ncy; abscissa: temperature, Centigrade.

Each group consisted of 100 larvae, collected as they emerged from hibernacula and stored in saturated air at room temperature for four hours before being placed in the equipment. The distribution shown for each group represents the summation of four observations taken during the first hour in the apparatus.

The results obtained with these four groups show that, despite the distorted distributions produced by the different lengths of the gradients of evaporation and by the effects of very high temperature, the peak for larvae of the second instar in a moist condition is always within the same range of evaporative rates. Note that the mechanical blockage of what might be termed the "normal" distribution of larvae of this type does not necessarily result in the formation of a secondary peak right at the point of blockage. The increase in numbers may occur one or two class intervals distant from that point. This is illustrated particularly in Figures 3a and 3c. It does not seem necessary to consider this fact to be of any special significance. A large number of different types of observations have shown that the larvae, when confronted by any type of barrier, characteristically ebb and flow against it. Thus, their movements account for the type of distribution obtained.

The results noted above were also plotted against temperature. Class intervals each spanned two Centigrade degrees. The distributions are shown in Figure 4. Figure 4a shows the data of Figure 3a, with similar correspondence between the other letters of the two figures.

The significant fact which emerges when the data are plotted separately is that the actual evaporation peak for the type of larva concerned remained constant, while the temperature aggregations, although appearing to be temperature "preferences," actually indicate that the larvae aggregated in a particular temperature zone in response to a rate of evaporation, not to a temperature. Thus, it seems permissible to state that, within the range of temperature available, and below about 36° C., the larvae of the second stage showed no preference for a narrow zone of temperature as long as a gradient of evaporation was present.

This statement also holds true for all the other instars when the appropriate temperature is substituted for 36° C. This may be illustrated with reference to Figures 5a and 5b, which show the maximum evaporation rate in which groups of sixth instars aggregated. Figure 5a shows the distribution obtained by summing four observations taken during the first hour on larvae which had been stored in saturated air for 12 hours at room temperature before being placed in the apparatus. Figure 4, 6a shows these data replotted against temperature, with the peak at 14°–16° C. Figure 5b shows the results obtained with the *same* group of larvae after they were fed and stored in saturated air for 12 days at about 4° C. The gradient was very moist, yet the evaporative rate at which the peak occurred was still 0.04 cu. mm. per minute, as in Figure 5a. On the other hand, when these data were replotted against temperature (Figures 4, 6b) the peak obtained lay at 24° C., as opposed to 14°–16° C. in the previous case. These data, incidentally, indicate the relative unimportance of acclimation to temperature as opposed to the importance of acclimation to evaporation in producing stable aggregations, thus stressing the fact that a temperature "preference" is more apparent than real.

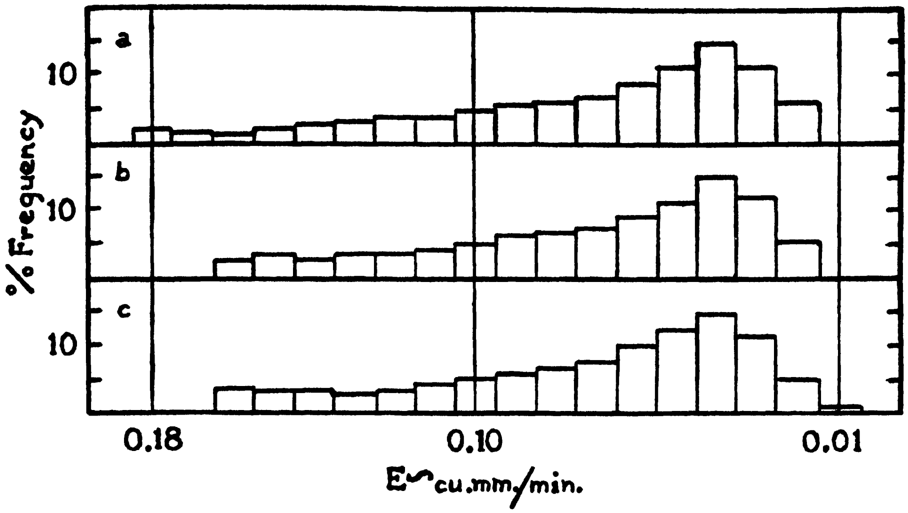

FIGURE 5. Aggregations in response to evaporation exhibited by two groups of initially moist sixth stage larvae: *a:* in a moist temperature gradient; *b:* the same group, in a very moist temperature gradient after 12 days' storage in saturated air at 4° C.; *c:* a group in an evaporative gradient held at a constant temperature of 20 6° C. Ordinate: percentage frequency, abscissa: rate of evaporation, cu. mm. per min.

The foregoing results show that, as long as a gradient of evaporation existed, it was impossible to obtain any data on the occurrence of zones of preferred temperature, in the accepted sense, for the larvae were always responding to the rate of evaporation and not to temperature at any level below about 36° C. In order to disclose any further response to temperature, it would be necessary to eliminate the evaporative gradient. This could be done only if the air in the temperature gradient were completely dry or completely saturated. Absolute dryness, if attained, would accomplish nothing, since the rate of evaporation from the larvae themselves would still increase with increasing temperature. On the other hand, it was observed that most larvae of all instars were turned back by completely saturated conditions in a gradient, and it was also found that uniformly saturated conditions at a constant temperature immobilized the insects rapidly. Nevertheless, a smaller gradient of the "bar" type was constructed using one radius of the brass disc as the floor. The sides were made by piling 2.5 × 40 cm. strips of blotter up to a height of 9 mm. The two sides were placed 5 cm. apart on the floor, and the ends were closed off with piles of blotters of similar height. A strip of plate glass served as the roof. The blotters were soaked with water and the gradient of evaporation within the enclosure was measured. This construction gave an evaporative gradient running from saturation to 0.03 cu. mm. per minute over the temperature range 10°–40° C. When the insects were placed in it, they gave the expected reactions, which were to turn back from both the saturated air at one end and the high temperature at the other, so that no additional information on temperature aggregations could be obtained. Consequently, the search for the somewhat tenuous temperature "preference" was abandoned.

Although the larvae exhibited no tendencies to aggregate in any patterns which could be construed as indicating preferred temperature ranges, they did possess a well-defined temperature sense. This was exhibited in response to radiant heat of temperatures above 36° to 38° C. by instars 2 to 6, or temperatures above about 28° C. by instar 1 (16). No extensive search was made to locate the temperature receptors, but tests with warm needles held 3 mm. from the body of a larva at different points showed that there was a definite gradient of sensitivity which increased cephalad. The head and the first four body segments were most sensitive to the radiating source. The last body segment was so insensitive that the needle had to be touched against it before a reaction was produced. This reaction was not necessarily the result of stimulation by temperature.

DISCUSSION

It has been shown that the larvae cannot be considered to exhibit a temperature preference in the accepted sense of the phrase. Since they are indifferent to temperature, below the upper limit which varies with the instar, it does not seem proper to consider the wide range below this limit as being a "preferred" zone. On the other hand, it has been shown that aggregations in response to evaporation were well-marked and consistent.

Work with aquatic organisms and with terrestrial animals living in a semi-fluid medium (Thomsen and Thomsen (12)) has demonstrated that temperature aggregations do exist. On the other hand, workers with terrestrial poikilotherms have not always considered the possible effects of atmospheric moisture on the animals observed. With few exceptions, those who have considered the role of atmospheric moisture in the complex governing the actions of animals have been content to speak of it in terms of relative humidity or saturation deficit.

If the effects of moisture are neglected altogether, difficulties may arise when attempts are made to interpret the actions of animals in gradients. For instance, Deal (3) measured the relative humidities within his apparatus, but neglected the effects of moisture in one experiment, where he reported that a braconid species moved to lower and lower temperatures in a gradient over a period of days, while a control group at room temperature died within the same time. He was unable to explain either the behaviour of the parasites in the gradient or their greater longevity. In view of the results of the present investigation, which showed that budworm larvae also moved lower in the gradients over a period of time, it would seem that the simplest explanation of the actions of the parasites is that they kept moving to lower rates of evaporation as they became desiccated. With a fixed amount of moisture in the apparatus, the lower rates of evaporation happened to be at lower temperatures. Deal also asked the question, "Why do certain insects, after being previously kept at a high temperature, have a lower preferred temperature than when previously kept at room remperature for the same length of time?" Unless the moisture conditions of storage are at saturation, the facts once more point to "desiccation" as the answer.

As noted in the introduction, rate of evaporation has been used throughout this work to demonstrate that there was a relationship between the actions of the insects and the moisture, rather than the temperature,

when these variables were presented in the form of gradients. To demonstrate any such relationship in combined gradients of two or more variables, it is necessary to show that the peak of each of a group of distributions always falls within a definite class interval of the variable related to the behaviour observed. Saturation deficiency and relative humidity are expressions of the amount of moisture in the air, but they do not take into account other factors which may affect the rate at which water vapour escapes from an evaporative surface. Thus, rate of evaporation, affected by other factors, is not directly proportional to either of the psychrometric expressions over a range of temperature. Therefore, if these expressions had been used here instead of evaporation, it would not have been possible to demonstrate that the insects, when in one particular condition, always aggregated within a definite zone of evaporation, as measured by the instrument used, over a range of temperature. This is illustrated by Table 1, which shows the positions of the peaks of the distributions of second and sixth stage larvae previously illustrated in Figures 3, 4 and 5 expressed in terms of rates of evaporation, relative humidity, saturation deficiency and temperature. These relationships were worked out from data obtained when the evaporimeter was calibrated for correlation of rates of evaporation with variable temperature and relative humidity, using solutions of sulphuric acid (cf. Wilson (17) and Buxton (2)) in a Dewar flask.

TABLE 1.—COMPARISON OF THE CONSTANCY OF THE POSITIONS OF PEAKS OF FREQUENCY DISTRIBUTIONS OF SECOND AND SIXTH STAGE LARVAE IN GRADIENTS OF MOISTURE AND TEMPERATURE, WHEN THESE DISTRIBUTIONS ARE PLOTTED AGAINST RATE OF EVAPORATION, PER CENT RELATIVE HUMIDITY, SATURATION DEFICIENCY AND TEMPERATURE

Instar	Gradient type	Evaporation, cu. mm./min.	Per cent R.H.	Saturation deficiency,* mm. Hg.	Temperature, ° C.
II	Constant room T.	0 14–0.13	42.5–45.5	10.463- 9.918	20.6
	Dry T.	0.14–0 13	44.5–47.0	11 004–10.509	22
	Moist T.	0 14–0 13	50.0–52.5	14.175–13.466	28
	Very moist T.	0.14–0 13	53.0–55.5	16 762–15.870	32
VI	Moist T.	0 04	72.4–73 5	3 309- 3.613	14–16
	Constant room T.	0.04	75.0	4 549	20.6
	Very moist T.	0.04	76.0	5.371	24

*e_m obtained for saturation deficiency calculations from: Handbook of chemistry and physics, pp. 1345-1346. 22nd ed. Cleveland. 1937.

Table 1 shows that, for each instar, only the rate of evaporation gave constant values for the positions of the peaks. It is especially important to note that in the constant temperature evaporation gradient, where every part of the available area was at 20.6° C., among the three methods of expressing moisture relations, only the rate of evaporation agrees with the positions of peaks obtained later in a gradient of temperature. Thus, while there is an objection that rates of evaporation measured with different

instruments are functions of the instruments and not the animals, nevertheless, the rates measured with the instrument used provide a closer expression of the factors influencing the behaviour of the insect than do the ordinary psychrometric expressions.

It follows from the above that gradients of evaporation still exist when attempts are made to keep either a uniform relative humidity or saturation deficiency over a range of temperature, or at the points in a gradient where peaks are observed. The chief danger which arises from the neglect of this point is that, if animals move to higher temperatures in moist air than in dry air, or when they themselves are moist, one is apt to conclude that there actually is a temperature preference, which is higher at such times. As shown in Figures 3 and 4, the animals actually may be following one particular range of evaporation which has shifted to a different temperature because the moisture content of the air in the apparatus has been changed. Some indication of this type of behaviour may be seen in the description by Gunn and Cosway (5) of the actions of cockroaches which were not indifferent to moisture.

It is rather pointless to speculate too much about the relative importance of the temperature preference of terrestrial poikilotherms when these speculations are based on observations on one species. Some animals have a temperature response unaffected by evaporation, and others, such as the spruce budworm, have an evaporation preference little affected by temperature. Nevertheless, if one searches the literature while thinking in terms of evaporation rather than temperature, no very close attention is required to collect examples which strongly suggest that re-investigation of several species would considerably reduce the number of terrestrial poikilotherms now grouped in the "temperature preference" classification. There is little point in citing all such papers, but examples may be found among the lengthy lists of references collected by Uvarov (15), Fraenkel and Gunn (4) and Deal (3).

In this paper, the spruce budworm has been used as an experimental animal to demonstrate an academic point. In subsequent papers in the series, further attention is given to similar points, but also, some attention is given to items which are of particular significance to the species itself.

SUMMARY

1. There was an upper limit of temperature beyond which larvae of the spruce budworm did not travel when allowed to move freely in combined gradients of temperature and rate of evaporation. The limit for the first instar was about 28° C., while that for instars 2 and 3 was about 36° C., and those for instars 4, 5 and 6 ranged from 37° to 38° C.

2. Below the upper limit of temperature, larvae of any instar were indifferent to temperature presented in gradient form down to and including 10° C., the lowest temperature available.

3. Below the upper limit of temperature, the larvae responded to the rate of evaporation, as measured by a micro-evaporimeter, and it was demonstrated that aggregations occurred within specific ranges of evaporation, regardless of where these ranges might be placed within the temperature range. Thus, the larvae of the spruce budworm cannot be considered to exhibit any temperature preference, in the accepted sense.

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THE EFFECTS OF TEMPERATURE AND MOISTURE UPON THE BEHAVIOUR OF THE SPRUCE BUDWORM, *CHORISTONEURA FUMIFERANA* CLEMENS (LEPIDOPTERA: TORTRICIDAE)

II. THE RESPONSES OF LARVAE TO GRADIENTS OF EVAPORATION[1]

W. G. WELLINGTON[2]

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INTRODUCTION

This paper is the second of a series dealing with the behaviour and activity of the spruce budworm, *Choristoneura fumiferana* (Clemens), in response to variable temperatures and rates of evaporation. In the first paper (4), it was demonstrated that larvae in apparatus containing gradients of temperature and atmospheric moisture aggregated in zones in response to evaporation rather than to temperature. The present paper describes the results of further investigations of the effects of evaporation upon aggregations of larvae observed in the laboratory.

EXPERIMENTAL MATERIAL AND APPARATUS

The majority of the experiments described in the following pages were performed during the same season as those listed in the first paper. Consequently, the insects used were obtained from the same general stock. Apparatus previously described (4) was employed during the investigations. This equipment consisted of the evaporimeter, employed to determine rates of evaporation in cu. mm. per minute, and the two types of apparatus for producing gradients of atmospheric moisture and of temperature: a linear, "bar" apparatus used to produce a graded scale of rates of evaporation at a constant temperature, and a disc-like apparatus, heated at the centre and cooled at the periphery, in which combined gradients of temperature and moisture could be established.

METHODS

As in the previous series of experiments, groups of 100 larvae were placed in the apparatus, and their positions were noted at the end of each 15-minute interval during any one hour. Positions once more were recorded first in terms of distance from a fixed point, rather than in terms of units of temperature or evaporation. Specific treatments of particular groups of larvae are described in the section outlining the observed results.

In addition to observations on groups of larvae, records were made of the behaviour of individual larvae of each of the six instars. Larvae were placed in the apparatus one at a time, and tracings were made of the paths individuals followed over fixed periods of time. An individual was kept under continuous observation during its first hour in the apparatus. Thereafter, if further information on its later behaviour was required, it was left to its own devices for one or more hours, after which another hour-long observation was made. During some observations, time marks were made on the tracings at intervals of one minute, so that the length of time spent in movement through a particular zone could be determined.

[1] Contribution No. 2573 from the Division of Entomology, Science Service, Dominion Department of Agriculture.
[2] Agricultural Scientist, Forest Insect Laboratory, Sault Ste. Marie, Ontario.

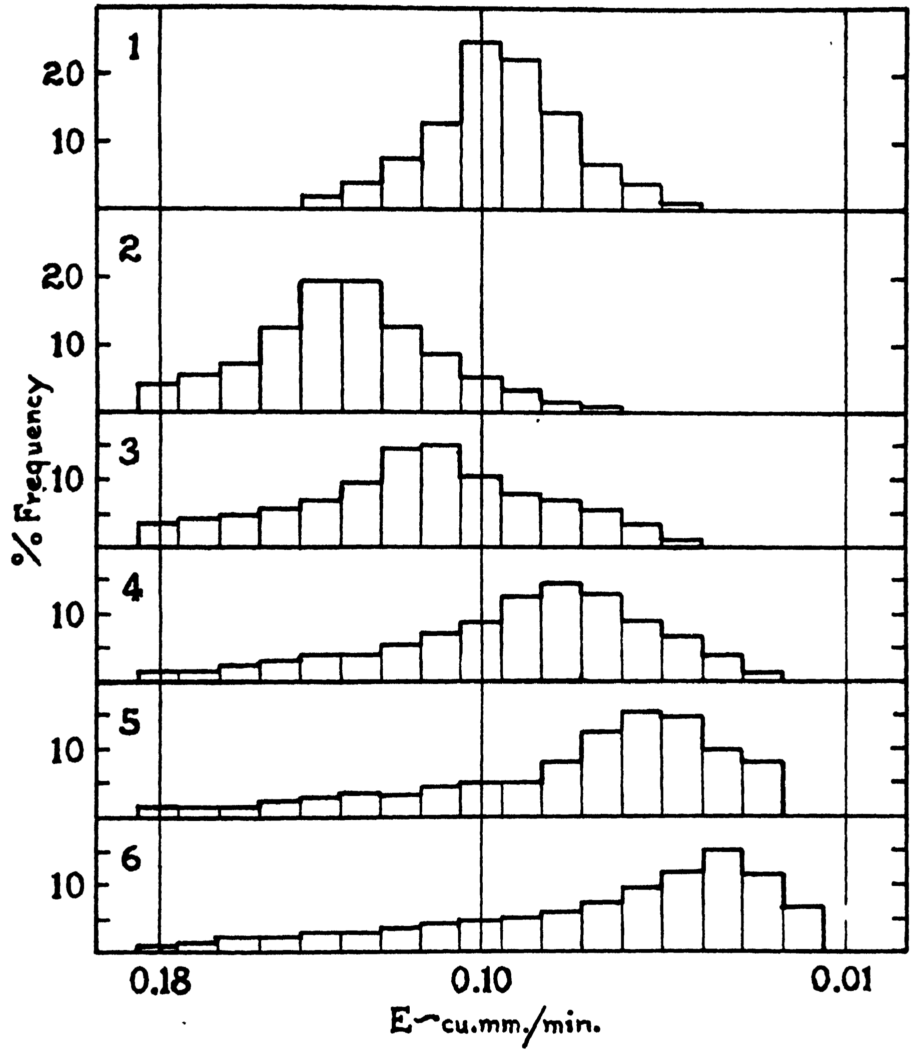

FIGURE 1. Inter-instar differences in the maximum rates of evaporation at which initially moist larvae aggregated: instars 1 to 6. Ordinate: percentage frequency; abscissa: rate of evaporation, cu. mm. per minute.

RESULTS

In the preceding paper, it was indicated that it was found possible to regulate to some extent the positions of larvae in a gradient by regulating the degree of saturation of the air to which they were previously exposed. Moreover, it was noted that, after about four hours in a saturated atmosphere, longer exposures at saturation did not result in any further movement of the peak of a frequency distribution (frequency of occurrence of individuals at definite rates of evaporation) to any higher rates of evaporation, when the larvae were finally placed in a gradient. The aggregations of larvae at these maximum rates were stable within an instar under the proper conditions, and hence the maximum rates provided useful standards for inter-instar comparisons.

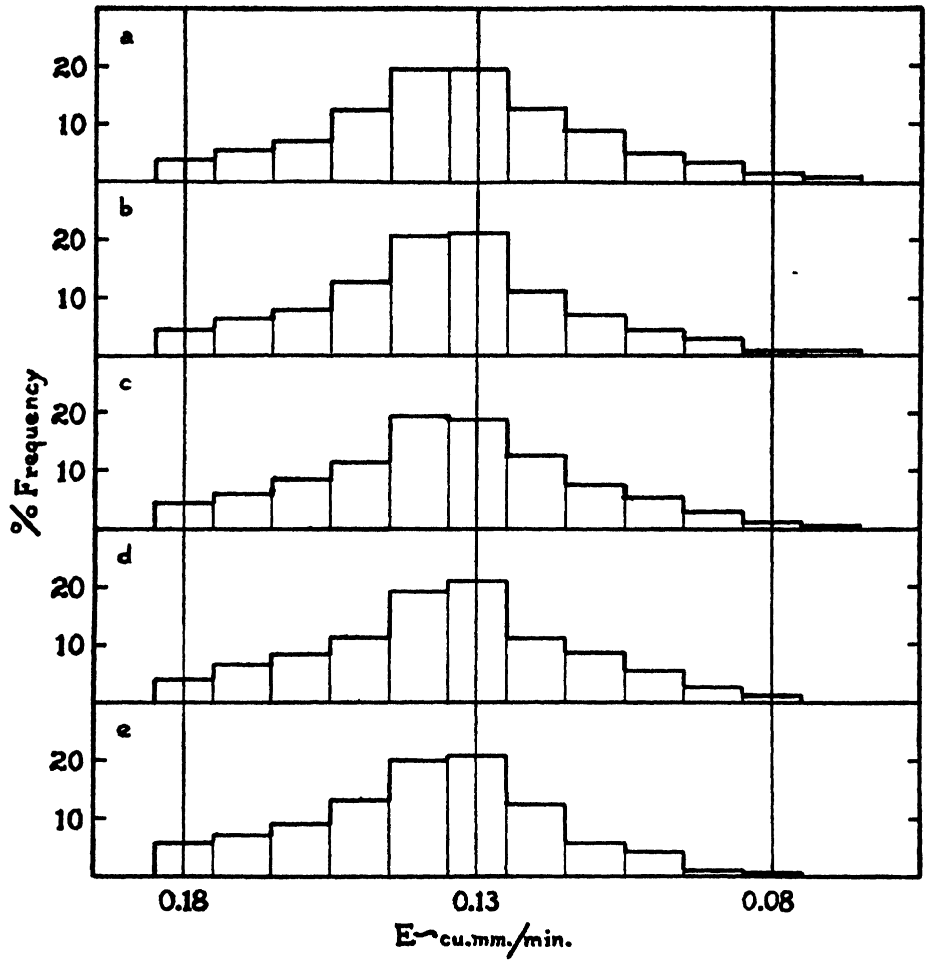

FIGURE 2. Intra-instar similarities in the maximum rates of evaporation at which initially moist larvae aggregated: instar 2. *a:* after 4 hours in saturated air; *b:* after 24 hours in saturated air; *c:* after 48 hours; *d:* after 7 days; *e:* after 14 days. Groups *a*, *b* and *c* stored at 20-21° C.; *d* and *e* at 4° C. Ordinate: percentage frequency; abscissa: rate of evaporation, cu. mm per minute.

The differences observed among the six instars are illustrated in Figure 1. The numbers at the corners of the diagrams refer to the instar numbers. Each instar is represented by 100 larvae. Larvae of instars 2 to 6 were stored for four hours in saturated air at 20° to 21° C. before being placed in the apparatus. Larvae of the first instar were so delicate that too many were injured in attempts to remove them from a wet surface, and, since they spun webs from which it was difficult to remove them without injury when they were stored under drier conditions, they had to be tested immediately after emergence from the egg masses, without further treatment. All groups were confined in the disc-like apparatus in moderately moist air (4). The results shown for each group are the summations of four observations taken during the first hour in the gradient. The differences among instars are shown clearly in Figure 1. These differences were verified by observations on additional groups noted below.

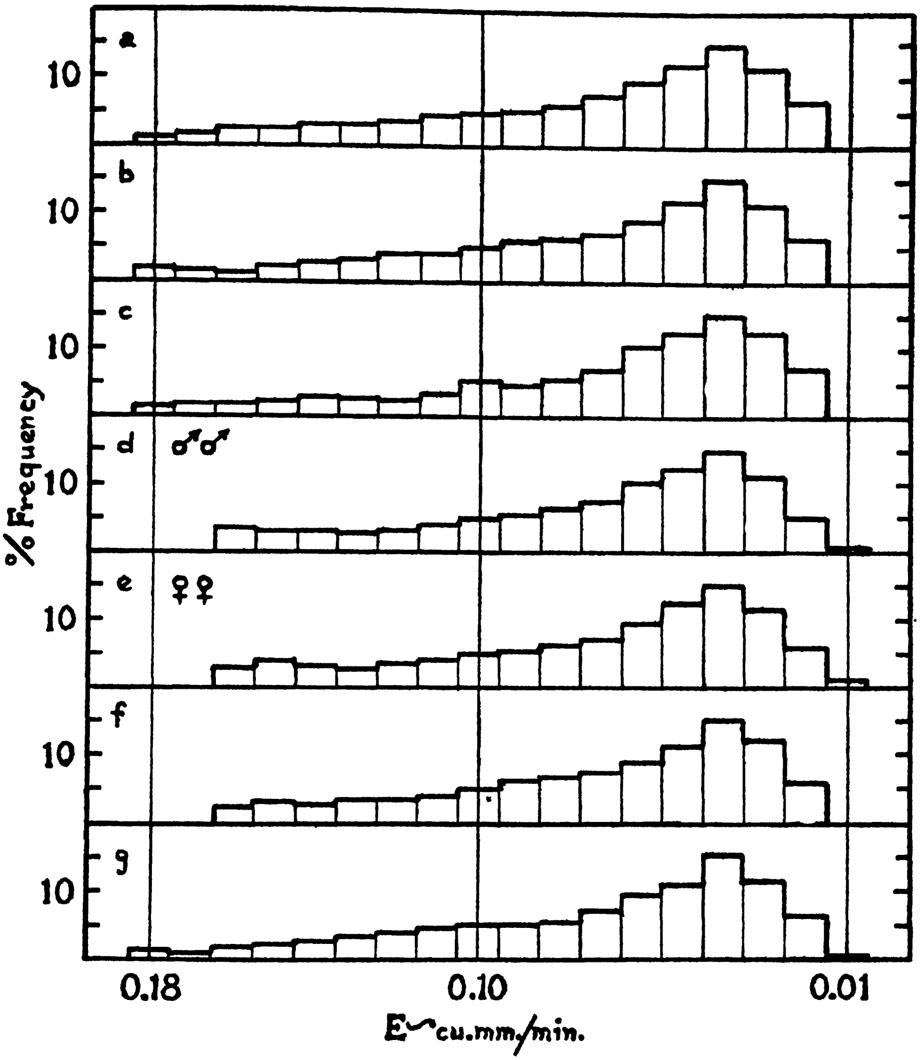

FIGURE 3. Intra-instar similarities in the maximum rates of evaporation at which initially moist larvae aggregated: instar 6. *a:* 22 days old; *b:* 32 days; *c:* 40 days; *d:* males, 32 days; *e:* females, 32 days; *f:* repeat of *b* after 12 days' storage at 4° C.; *g:* field-collected larvae, age unknown. Groups *a*, *c*, *d*, *e* and *g* previously stored for 4 hours in saturated air at 20-21° C. Group *b* stored for 12 hours. Groups *a*, *b*, *c*, and *g* observed in a moist temperature gradient; *d* and *e* in an evaporative gradient held at a constant temperature of 20° C.; *f* in a very moist temperature gradient. Ordinate: percentage frequency; abscissa: rate of evaporation, cu. mm. per minute.

Groups of larvae of each instar were observed in order to determine whether: (*a*) the slope or the length of the evaporative gradient; (*b*) the presence or absence of a temperature gradient; (*c*) previous treatment with saturated air for periods longer than four hours; (*d*) sex, or (*e*) age differences produced any intra-instar differences in the stable, first-hour aggregations observed for each instar.

The term "age" as used in work on instars 2 to 6, refers to the age in days calculated from the time of emergence of the second stage larvae

from hibernacula. Thus, it refers to the period of seasonal activity only, and does not include the period spanned by the preceding winter months. The ages of first stage larvae were reckoned from the time of eclosion from the eggs.

A total of 32 additional groups were observed, confirming the inter-instar differences shown in Figure 1. Sample observations from the additional series are illustrated in Figures 2 and 3. Various differences of age, sex or treatment are listed in the legends of the figures. The marked intra-instar similarities shown among the groups of the second and sixth instar larvae illustrated also were exhibited by each of the remaining instars. Thus, for larvae stored in saturated air before being placed in the apparatus, and observed during the first hour in the gradients, the results may be summarized in the following way.

Inter-instar Differences

(*a*) Chi-square comparisons of distributions of any two instars gave $P < 0.01$, regardless of the type of gradient employed or of similarities in the ages of the larvae. For instance, second and third stage larvae, all seven days old, still preserved the differences in response to evaporation illustrated in Figure 1.

Intra-instar Similarities

(*a*) Within any instar, chi-square tests of groups observed in the same type of gradient gave $P > 0.90$, regardless of differences in the ages or sex of the larvae, or in periods of previous treatment longer than four hours (see Figure 3).

(*b*) Within any instar, chi-square tests of distributions of groups tested in different types of gradients gave $P > 0.10$ or $P < 0.05$, depending on the types of gradients compared. The slopes of the gradients did not affect the distributions significantly. If the lengths of the gradients differed so much that $P < 0.05$ for two groups, then the region of the mode of each distribution (the instar rate) was always at the same rate of evaporation. Thus, while the lengths of the gradients affected the ends of the distributions in some instars, they did not affect the positions of the peaks of the distributions.

(*c*) The presence or absence of a temperature gradient affected the distributions only by affecting the lengths of the evaporative gradients used with variable temperature (see also the discussion of the upper limit of temperature in the previous paper of this series).

It has been pointed out (4) that it was only after the provision of conditions which would give constancy of the maximum rate at which larvae of an instar aggregated that any consistent differences between instars could be established. Before the correct method of previous treatment was found, several thousand records were taken and had to be discarded because they were based on populations mixed with respect to previous exposure to moisture. A specimen from these early data is included to illustrate the type of distribution obtained. This figure also is useful for interpreting what occurred in any group in later hours in the gradients. The second instar is used as an illustration.

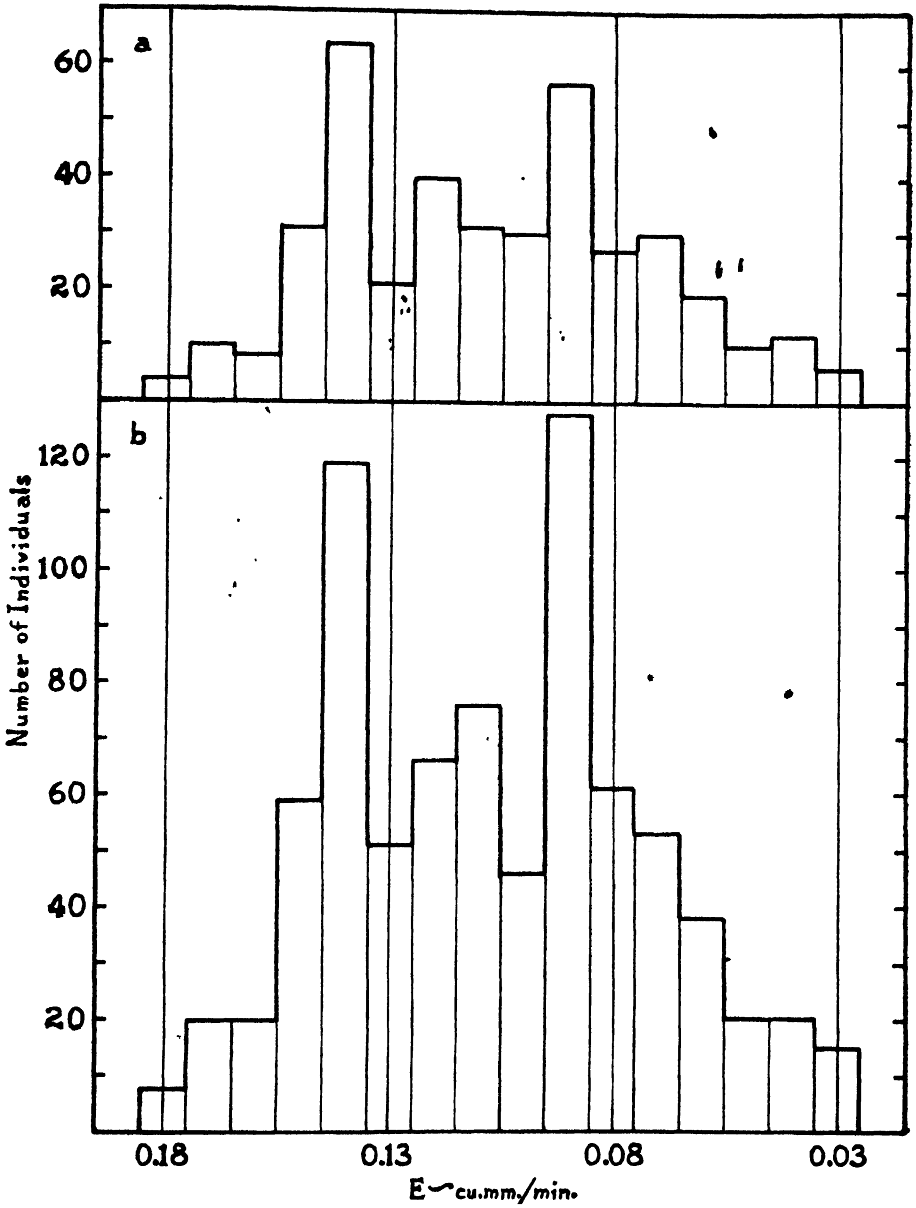

FIGURE 4. Distributions obtained when larvae were desiccated to varying degrees: instar 2. *a:* The group shown in Figure 2*a* after 3 hours in the moist temperature gradient; *b:* a group of larvae not treated with saturated air before being placed in the gradient; observation taken during the first 1½ hours. Ordinate: number of individuals; abscissa: rate of evaporation, cu. mm. per minute.

Figure 4b shows a distribution exhibited by 100 freshly collected, but untreated larvae of the second stage during the first 1½ hours of their confinement in the apparatus. This distribution was obtained by summing the results of eight observations during the period. There are three peaks, only one of which agrees with the maximum rate previously shown for the

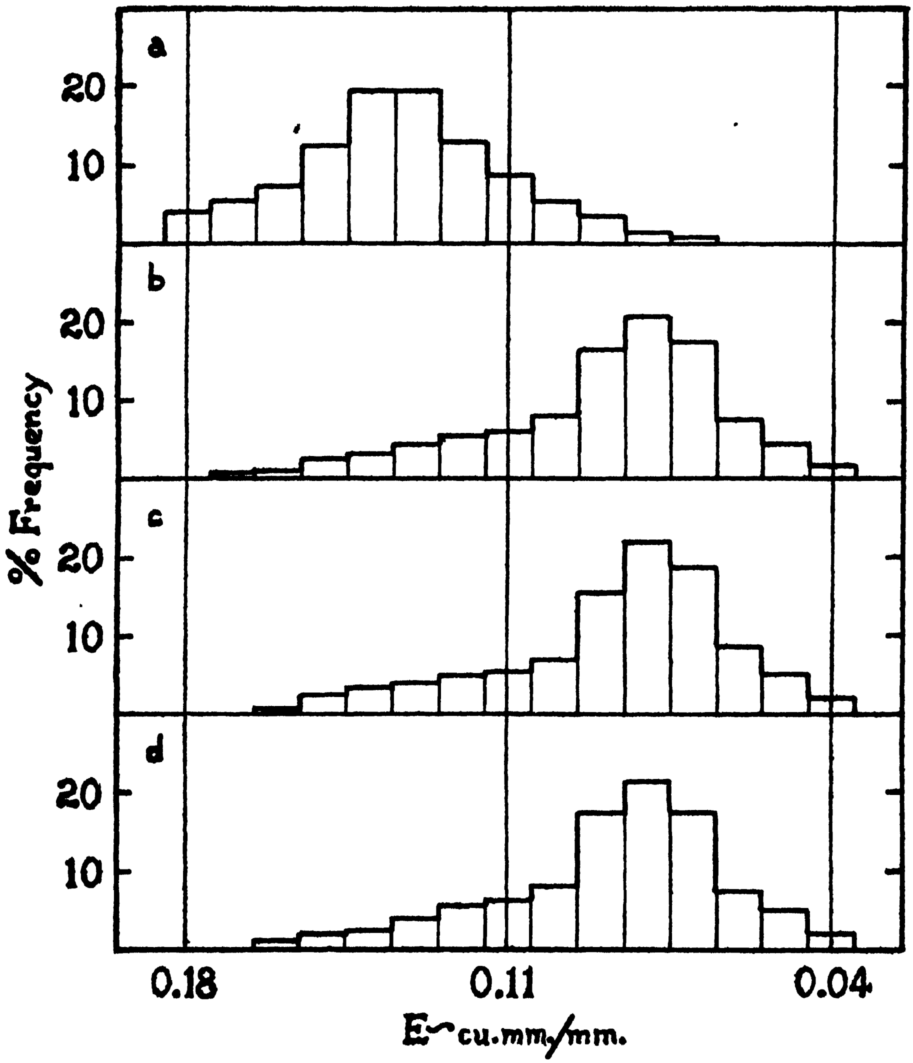

FIGURE 5. The effects of prolonged or severe desiccation upon the distribution of larvae in an evaporative gradient: instar 2. *a:* Distribution obtained in the first hour (Figure 2*a* replotted for comparison; *b:* the same group after 24 hours in the moist temperature gradient; *c:* a group previously dried for one hour in calcium chloride, observed for one hour in a moist temperature gradient; *d:* a group which had an original distribution similar to that of group *a*, but which was held for 24 hours in an evaporative gradient kept at a constant temperature of 20° C. Ordinate: percentage frequency; abscissa: rate of evaporation, cu. mm. per minute.

second instar (Figures 1 and 2). This type of distribution occurred frequently when untreated populations were used, but sometimes one or two of the three peaks were missing, or the two lower peaks were at different positions in the gradients. Such multi-modal distributions often occurred after a group had been in a gradient for a time, even if the original distribution observed had been normal for the instar. This may be illustrated further.

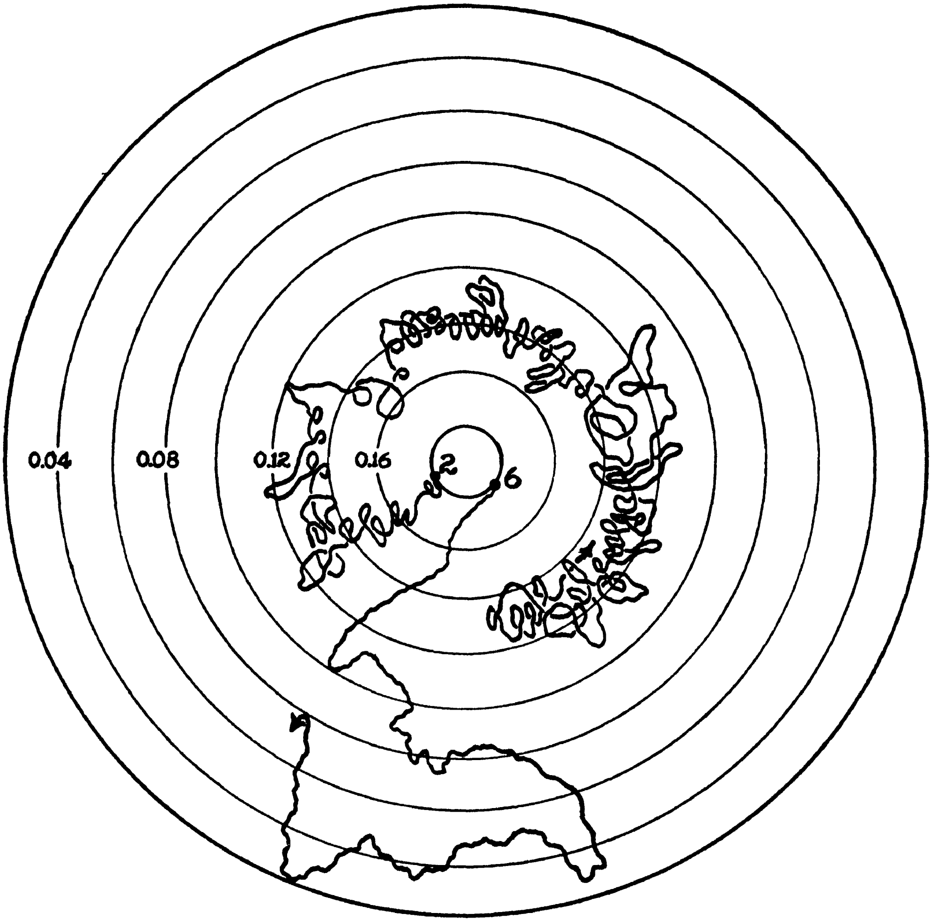

FIGURE 6. Tracks of larvae in a gradient of evaporation: instars 2 and 6. One-hour tracks of untreated larvae. Disc figures: rate of evaporation, cu. mm. per minute.

If second stage larvae were correctly exposed to saturated air for at least four hours, the typical distribution, such as any one of those illustrated in Figure 2, was obtained. Such distributions were stable for at least one hour and could persist for $2\frac{1}{2}$ to 3 hours, depending on the care with which the larvae were treated during previous storage (cf. 4). At the end of $2\frac{1}{2}$ or 3 hours, however, the typical distribution began to break down. Figure 4a shows a distribution obtained by summing four observations taken between hours 3 and 4 on the 100 larvae which gave the original distribution of Figure 2a. It will be seen that Figure 4a is very similar to Figure 4b, which was obtained from untreated larvae during their first hour in the apparatus.

During the next 12 hours larvae were in the apparatus, almost any type of distribution could be obtained. The only thing common to the many types was that the maximum evaporation peak observed was never

higher than the original maximum noted for the instar. During the last 6 hours of a 24-hour period, a new, stable distribution occurred at a considerably lower level in the gradient. The change which occurred over the 24 hours may be seen in Figure 5.

Figure 5a shows the same group illustrated in Figure 2a, re-drawn here for comparison. Figure 5b shows the distribution exhibited by this group after 24 hours in the apparatus. Both of these may be compared to the 3 to 4 hour distribution, an intermediate type, shown in Figure 4a. Figure 5c shows the distribution obtained during the first hour from four observations on a group of 100 larvae which had been dried in calcium chloride for one hour before being placed in the apparatus.

Some further information on the behaviour of larvae in gradients was obtained by observing individual larvae for hour-long periods. Figure 6 shows examples of two types of one-hour tracks which individual larvae followed in a concentric evaporation gradient. Each track begins with a dot and the direction of the arrow at the end of the track shows the direction in which the larva was moving at the end of the observational period. Numbers at the dots refer to the instar numbers. It must be emphasized that the types of paths shown for each instar were not peculiar to the instar, but might be exhibited by individuals of any instar. Thus, a sixth stage larva might, on occasion, follow a convoluted path much like that of the second stage shown in the figure. Moreover, since these were individual larvae, the "preferences" indicated did not necessarily agree with the group "preferences" obtained for the instars concerned.

Figure 7 shows two tracks obtained from one individual of the third instar, while it was in two different states. Track (*a*) shows the path of the larva during its first hour in the gradient. The larva was removed from the foliage on which it was feeding and placed directly in the gradient without any special treatment. Track (*b*) shows the path taken by the larva after it had been picked up while moving to a low rate of evaporation at the end of track (*a*) and returned to the original starting point. Figure 8 presents the information of Figure 7 in a different manner. The histograms indicate the time, in minutes, spent within the different zones of evaporation during the course of each of the consecutive, hour-long periods.

It was found that light, food and foreign matter could be used to draw larvae of different instars from their particular zones of aggregation. Under certain temperature conditions (3), all stages reacted positively to diffuse light, and could be drawn into a zone of even completely saturated air by darkening the rest of the gradient. Within this zone, they soon became immobilized and so were trapped in it. They also could be drawn into areas where rates of evaporation were excessively high by the same method. In the room temperature evaporation gradient, larvae of all instars were held by the light in a high rate of evaporation until they became moribund from desiccation. In the combined temperature and evaporation gradients, larvae could not be drawn much above the 36° isotherm by light (3) or any other factor. It should be emphasized that consistent responses could be obtained only when diffuse light was employed to draw larvae along or around apparatus (cf. 3).

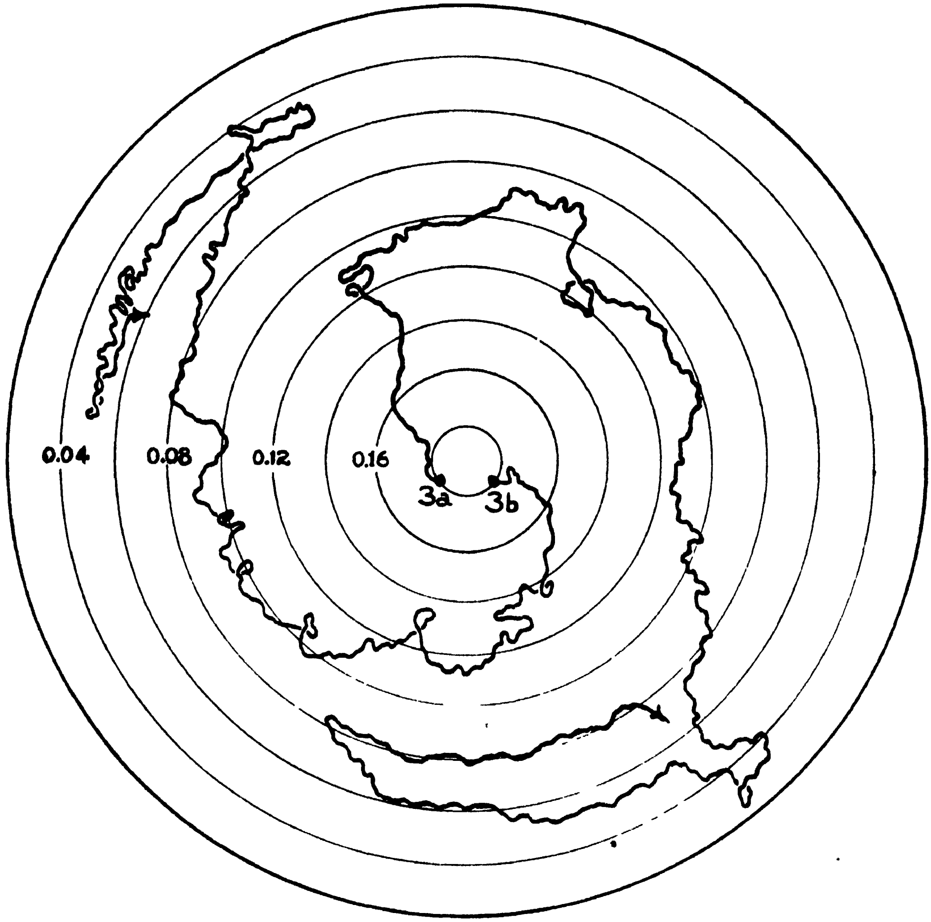

FIGURE 7. Tracks of larvae in a gradient of evaporation: instar 3. *a:* one-hour track of freshly-collected, untreated larvae; *b:* the same larva, collected while moving at a low rate of evaporation and observed for an additional hour. Disc figures: rate of evaporation, cu mm. per minute.

Instars 2 to 6 responded to the presence of food in the apparatus when they became sufficiently hungry. Individual needles were used so that the larvae could not climb off the floor of the disc as they could have done if twigs had been used. The larvae did not move directly to the needles, but, if they encountered them, they remained by them until the needles began to dry.

DISCUSSION

It has been shown that suitable previous treatment revealed differences in the rates of evaporation at which larvae of the six instars aggregated. The groups in these zones consisted of insects conditioned by saturated air to a point at which their retained water apparently was at its possible maximum. In this condition, they reacted to dry air (cf. Bentley, 1), but exhibited instar differences in the maximum rates of evaporation to which they would move.

Despite the fact that these differences were well-marked, as illustrated in Figure 1, and consistent, as noted in the preceding section, it also has been shown that they were short-lived, existing for a maximum period of three hours. Within this interval, intra-instar similarities could be demonstrated. After this interval, multimodality, as illustrated in Figure 4, appeared, and intra-instar comparisons became impossible.

The frequent occurrence of the type of distribution shown in Figure 4b when untreated populations were used might have been interpreted as indicating the presence of two or more physiological races differing in their responses to evaporation (cf. Wilkes, 5). The facts that only one of the peaks ever occurred in the same place and that, occasionally, regular distributions were obtained did not lend too much weight to this hypothesis.

The observations illustrated in Figures 4 and 5, when repeated for each instar, showed conclusively that the positions of peaks of distributions were affected by the degree of desiccation of the larvae. Thoroughly moist larvae aggregated at the instar rates previously illustrated. Larvae which were partially desiccated reversed their reaction to dry air and tended to aggregate at lower rates of evaporation. The drier the larvae, the lower the rates of evaporation at which they aggregated, and the sooner they collected in such zones. This last point is emphasized by Figure 5c, showing larvae which had been dried by calcium chloride before being placed in the apparatus.

Thus, the multimodality exhibited for several hours by larvae which were initially very moist or mixed in this respect (Figure 4) was brought about by larvae of varying degrees of desiccation aggregating in different zones at the same instant. Observations on individual larvae, such as those illustrated in Figures 7 and 8, showed that any one larva might recover from the effects of desiccation by moving to a zone of lower evaporation, and later return to the original zone or to an intermediate one (see also Figure 6). As the time of exposure in the gradient was prolonged, and the larvae remained unwatered and unfed, the highest rate of evaporation to which these larvae returned for any length of time became lower and lower. Thus, the larvae were gradually forced to lower and lower zones in the gradient. Eventually, this resulted in a recurrence of stable distributions which lacked additional peaks, such as that shown in Figure 5b. Since individual larvae exhibited the same sort of behaviour as that shown by a group, it was not necessary to call upon the concept of physiological races to assist in the interpretation of the movements of the groups. It was thought for a time that there was some evidence of differentiation among individual larvae, since it was noticed that some individuals observed for one hour remained in a narrow zone, while others fluctuated as described above. However, it was found that any one larva might exhibit both types of behaviour, so the problem was left at that point. If races exist, they did not indicate their presence by exhibiting different responses to evaporation in any of the experiments reported here.

It should be emphasized that the aggregations at the low rates illustrated in Figure 5 were not at the minimum rates for the instar. About all that may be said concerning the lowest rates to which larvae would move is that, if larvae were desiccated sufficiently, they all eventually approached,

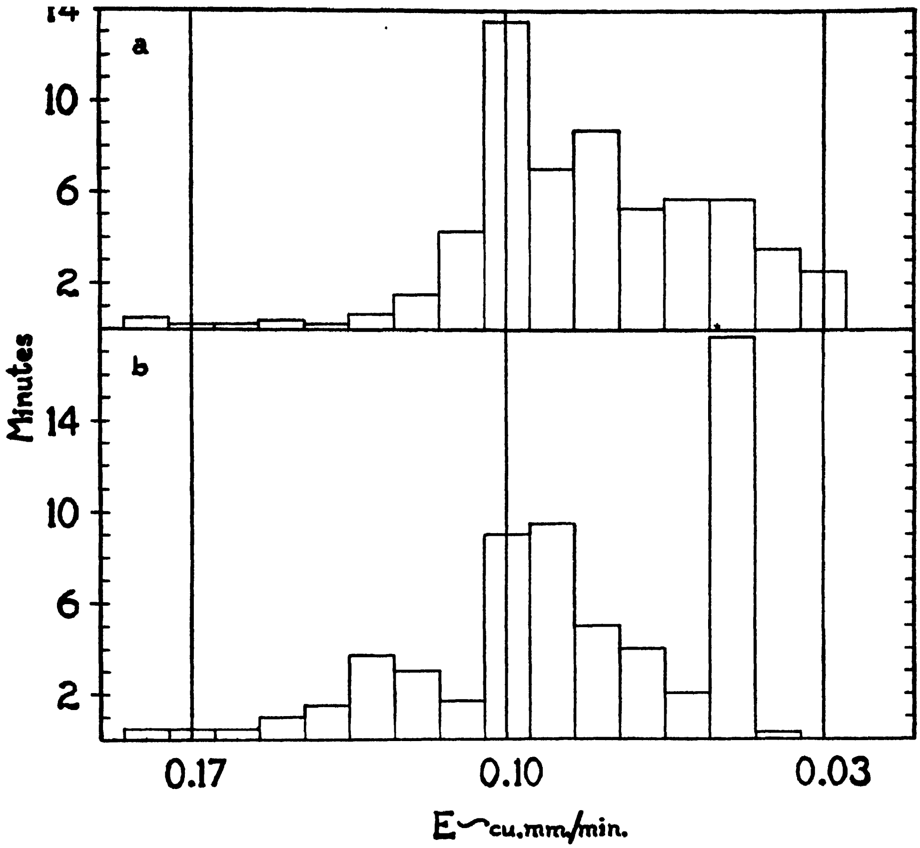

FIGURE 8. Quantitative presentation of the tracks of the third instar larva shown in Figure 7. The time, in minutes, spent at different rates of evaporation during each hour in the gradient. *a:* during the first hour; *b:* during the second hour.

but seldom entered, the zone of completely saturated air. There were no instar differences in this respect, although, as shown in the preceding illustrations, the later instars responded initially to rather low rates.

Tracks such as those illustrated in Figures 6 and 7, particularly when translated into terms of the amounts of time spent in restricted areas (Figure 8), showed some features of the mechanism of the reaction to evaporation. For instance, Figure 8 shows that an individual larva spent considerably more time at definite rates of evaporation, the levels of which varied with the condition of the larva. Spruce budworm larvae of instars 2 and 3, and larvae of the first instar lacking a suitable substrate for spinning, moved almost constantly while in the apparatus, differing in this respect from some species of insects commonly used in preferendum studies. Observations of their movements revealed a number of reasons for the excess time spent in restricted zones. The reasons are listed below.

Outside the zone, movement was rapid, and orientation was direct, with the path leading across the iso-lines of the gradient. As the zone was approached, and, often, after it had been entered, a larva appeared to move at a slower rate. Although the actual speed of movement was not decreased

and sometimes, actually increased, more time was spent in covering a given distance, because there were more frequent momentary hesitations during which tests of the surroundings were made by lateral body movements. In addition to these comparisons of the intensities of stimulation, there was a good deal of "virtual inactivity" (Gunn and Pielou, 2), during which the larva kept moving, but turned so sharply and so continuously that it covered very little territory. Akin to this type of behaviour was an increase in the actual amount of turning shown by some individuals. The net result was that the frequent hesitations, "virtual inactivity" and increased amount of turning more than counterbalanced the fairly direct movement outside the zone. Hence, more time was spent at the rate of evaporation within the zone than at any other rate. At the upper and lower limits of evaporation, beyond which a larva did not move, a sharp, "avoiding" reaction occurred.

Larvae of instars 4 to 6 frequently exhibited the same behaviour patterns as those noted above. In addition, actual cessation of locomotion sometimes occurred when the larvae reached zones in which the instar evaporation rates prevailed. Larvae, on entering these zones, might remain stationary, except for head movements, five or ten minutes at a time. This tendency to stop within the zone of the instar rate (or at lower rates, if the larvae were desiccated) was most marked among larvae of the sixth instar.

SUMMARY

1. Larvae conditioned to saturated air showed inter-instar differences in their responses to rates of evaporation during their first three hours in a gradient.

2. Different groups of similarly conditioned larvae of any one instar showed similar responses to evaporation, regardless of differences in the ages or sexes of the larvae, or of differences in the slopes of the gradients. The lengths of the gradients affected distributions of larvae only by restricting the movements of individuals on the outer fringes of a group.

3. The drier larvae became, the lower the rates of evaporation at which they aggregated. Partial, temporary recoveries from desiccation could be observed at the lower rates, but, eventually, all larvae approached, but did not enter, the zone of saturated air.

4. The mechanism of the response to evaporation contained several behaviour elements. More time was spent within a zone of evaporation than outside it because, within the zone, time spent in increased amount of turning, "virtual inactivity" and more frequent hesitations for tests of the surroundings more than counterbalanced time spent in direct movements outside the zone.

ACKNOWLEDGMENTS

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EPIDEMIOLOGY OF RUST IN WESTERN CANADA AS INFLUENCED BY THE INTRODUCTION OF STEM-RUST RESISTANT VARIETIES[1]

B. PETURSON[2]

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INTRODUCTION

The recent introduction of rust-resistant varieties of wheat and oats in the western plains region of the United States and Canada has gone far towards eliminating one of the major hazards to cereal production in that area. It is generally recognized that since the introduction of these varieties rust losses have been drastically reduced. As might have been expected, the substitution of resistant for susceptible varieties over an area of several million acres has profoundly affected the pattern of rust development, particularly in the northern part of the western plains region. The number of stem-rust spores present in the air over Western Canada during the summer months has diminished. The spread of stem rust westward and northward into the areas of Western Canada where susceptible varieties of wheat and oats are still grown has been restricted. Significant changes have taken place in the relative prevalence of races of stem rust of oats and leaf rust of wheat. These secondary effects, resulting from the introduction of rust-resistant varieties, are considered to be of sufficient importance from both the economic and scientific viewpoints to warrant detailed examination. It is with this question that the present paper deals.

In 1937, small amounts of seed of stem-rust resistant varieties of wheat and oats were released to farmers in the area of Western Canada subject to rust attack. With the seeding of the 1939 acreage, the change-over from susceptible to resistant varieties was all but completed and, in that year, almost 80 per cent of the wheat acreage and much of the oat acreage in this area was sown to stem-rust resistant varieties. In this study, therefore, the year 1938 and previous years are placed in the period in which susceptible varieties were generally grown, and the year 1939 and subsequent years are placed in the period in which stem-rust resistant varieties held the predominant position.

EXPERIMENTAL METHODS

The effect of the substitution of stem-rust resistant varieties for susceptible ones on the epidemiology of cereal rusts in Western Canada has been determined by comparing stationary spore-trap data, uniform rust-nursery data, and physiologic-race survey data, over a period of several years prior to and subsequent to the general introduction of resistant varieties in 1939; and by comparing the performance of a susceptible variety, Marquis, and a resistant variety, Regent, in uniform field tests throughout this area.

All the spore-trap data, the rust-nursery data, and the yield data were analysed statistically to determine the significance of the differences between the various sets of data compared. In all the statistical analyses carried out, analysis of variance methods were employed.

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INFLUENCE OF CHANGE FROM SUSCEPTIBLE TO RESISTANT VARIETIES ON THE PREVALENCE OF AIR-BORNE INOCULUM OVER MANITOBA

Stationary spore-trap slides were exposed each summer from 1926 to 1946 at three stations in Manitoba—Morden, Brandon, and Winnipeg. The numbers of stem and leaf-rust spores caught on the slides were recorded. Table 1 gives, for the Morden and Brandon stations, the total numbers of stem-rust spores caught on a square inch of slide during each 10-day period in June and July over an 8-year period, 1931 to 1938, when susceptible varieties were grown, as well as over an 8-year period, 1939 to 1946, when stem-rust resistant varieties predominated. It also gives, for the Winnipeg station, similar data for the 7-year periods, 1932 to 1938 and 1940 to 1946. This table shows that at all three stations the spore counts were much lower for the period when resistant varieties predominated than for the period when susceptible varieties were grown. For each station the reductions in spore counts were statistically significant. The table further shows that the disparity between spore counts for the two periods was much greater towards the end of the season, at which time locally produced inoculum predominated in the air, than at the beginning of the season when wind-borne inoculum from more distant infection sources predominated.

TABLE 1.—THE TOTAL NUMBER OF STEM-RUST SPORES INTERCEPTED ON 1 SQ. IN. OF SLIDE AT MORDEN, BRANDON, AND WINNIPEG DURING 10-DAY INTERVALS IN JUNE AND JULY FOR PERIODS PRIOR TO AND AFTER THE GENERAL INTRODUCTION OF STEM-RUST RESISTANT VARIETIES IN 1939

Exposure interval	Morden		Brandon		Winnipeg	
	8-year period		8-year period		7-year period	
	1931-1938	1939-1946	1931-1938	1939-1946	1932-1938	1940-1946
June 1-10	16	2	35	8	19	13
June 11-20	141	19	49	23	62	18
June 21-30	233	94	98	71	844	331
July 1-10	2,086	971	392	214	607	426
July 11-20	29,107	7,057	8,015	551	6,352	2,026
July 21-30	178,471	24,072	57,288	2,814	71,480	5,158
Total spores	210,054	32,215	65,877	3,681	79,364	7,972

The total numbers of leaf-rust spores caught on each square inch of slide, recorded in 10-day exposure intervals during June and July, are given in Table 2 for the two 8-year periods under review. The data presented in this table show that with the introduction of stem-rust resistant varieties there was no reduction in air-borne leaf-rust inoculum. In fact, at the Brandon station, there was a significant increase in the numbers of leaf-rust spores caught on the slides following the introduction of stem-rust resistant varieties. At the other two stations there was no significant difference in the numbers of spores caught on the slides for the 8-year periods before and after the introduction of stem-rust resistant varieties. This result may be attributed to the fact that none of the stem-rust resistant varieties was very highly resistant to leaf rust. One of these varieties, Thatcher, which since 1939 has occupied from one-third to one-half of the

TABLE 2.—THE TOTAL NUMBER OF LEAF-RUST SPORES INTERCEPTED ON 1 SQ. IN. OF SLIDE AT MORDEN, BRANDON, AND WINNIPEG DURING 10-DAY INTERVALS IN JUNE AND JULY FOR PERIODS PRIOR TO AND AFTER THE GENERAL INTRODUCTION OF STEM-RUST RESISTANT VARIETIES IN 1939

Exposure interval	Morden		Brandon		Winnipeg	
	8-year period		8-year period		7-year period	
	1931-1938	1939-1946	1931-1938	1939-1946	1932-1938	1940-1946
June 1-10	16	127	58	126	35	30
June 11-20	889	267	137	235	578	280
June 21-30	1,610	1,241	604	1,237	1,058	2,939
July 1-10	11,854	9,271	781	2,676	1,186	2,552
July 11-20	53,160	39,738	1,315	9,615	9,342	9,645
July 21-30	92,300	46,728	11,711	22,479	29,201	14,552
Total spores	150,829	97,372	14,606	36,368	41,400	29,998

wheat acreage in Manitoba and eastern Saskatchewan, is much more susceptible to leaf rust than Marquis, and is quite as susceptible as Ceres to this rust. It was these two varieties that Thatcher largely displaced. Two other important stem-rust resistant varieties, Regent and Renown, although very much more resistant to leaf rust than Marquis and Ceres, are moderately susceptible to certain races of leaf rust and have in some years carried considerable leaf-rust infection. Moreover, with the exception of Ajax, none of the stem-rust resistant varieties of oats grown in this area possesses any resistance to crown rust. Ajax has some mature-plant resistance to certain races of crown rust. With the introduction of these varieties of wheat and oats, therefore, there was no marked change in air-borne leaf-rust inoculum.

EFFECT OF GROWING RESISTANT VARIETIES IN THE RUST AREA ON THE NORTHWARD AND WESTWARD SPREAD OF RUST

Uniform rust nurseries in which both resistant and susceptible varieties were grown have been located over a period of years at several places in Western Canada. Rust readings have been taken on these varieties every year since 1939. The longest continuous period for which rust readings are available, prior to the introduction of rust-resistant varieties, is a 5-year period from 1925 to 1929, inclusive. This period is fairly representative of the rust conditions that prevailed during the period that susceptible varieties were grown, for, according to Craigie (1), it includes one heavy rust year, 1927; one medium rust year, 1925; and three light rust years, 1926, 1928, and 1929. A comparison of rust readings on the susceptible varieties Marquis and Little Club in the uniform rust nurseries for this period with rust readings on the same varieties in rust nurseries during the 5-year period 1942 to 1946, shows that stem-rust infection on these varieties was much heavier in Western Canada during the period in which stem-rust susceptible varieties predominated (Table 3). Furthermore, the farther northward and westward the areas were located the greater was the difference between the highest rust readings for the two periods under consideration. These findings indicate that the northward and westward spread of stem rust was appreciably less during the latter period.

TABLE 3.—THE PERCENTAGES OF STEM RUST OF WHEAT FOR THE PERIOD 1925 TO 1929, AND THE PERIOD 1942 TO 1946, ON SUSCEPTIBLE VARIETIES GROWN IN UNIFORM RUST NURSERIES IN WESTERN CANADA

Area	Average infection for period (per cent)		Highest infection for period (per cent)	
	1925-1929	1942-1946	1925-1929	1942-1946
Eastern Manitoba	68	36	90	55
Mid-western Manitoba	66	25	95	60
Eastern Saskatchewan	22	17	80	60
Mid-western Saskatchewan	27	1	68	10
Western Saskatchewan	13	Trace	68	Trace
Eastern Alberta	1	Trace	Trace	Trace

EFFECT OF RESISTANT VARIETIES ON THE PREVALENCE OF DIFFERENT RACES OF RUST

Collections of stem rust of wheat (*Puccinia graminis Tritici* Erikss. & Henn.), leaf rust of wheat (*P. triticina* Erikss.), crown rust of oats (*P. coronata* Corda var. *Avenae* Erikss. & Henn.), and stem rust of oats (*P. graminis Avenae* Erikss. & Henn.) have been made and identified each year since 1925, from many separate localities in the Prairie Provinces of Western Canada.

The introduction of stem-rust resistant varieties has apparently had no effect on the wheat stem rust physiologic-race complex in Western Canada. The relative proportions of the races have not changed materially since the general advent of resistant varieties. However, a new race of stem rust, 15B, that can heavily attack the presently grown resistant varieties was found in one locality in Manitoba in 1946.

With respect to leaf rust of wheat the situation is somewhat different. The varieties Regent and Renown, during the first few years after their release, proved to be at least moderately resistant to leaf rust. But during the past several years new races of leaf rust, such as race 128, and certain biotypes of races 5 and 15, have appeared and increased. These races, reported by Johnson and Newton (2), are able to attack Regent and Renown heavily, and both varieties have carried heavy infections in many localities in Western Canada in the three years, 1944 to 1946.

A very marked change has taken place in the relative prevalence of the races of stem rust of oats since the new stem-rust resistant varieties were distributed. Before the varieties Vanguard (released in 1937) and Ajax and Exeter (released in 1943) became the predominant varieties in the rust area, the common races of oat stem rust, 1, 2, and 5, to which these varieties are all highly resistant, comprised over 90 per cent of all the races isolated from collections of stem rust of oats made in Western Canada. Races 8, 10, and 11, to which these three varieties are susceptible, were only rarely collected and in some years were not even represented among the races isolated. In 1943, a notable increase in the prevalence of races 8, 10 and 11 was apparent, and each year since this increase has continued. In 1945 and 1946, these three races comprised 33 per cent of the oat stem-rust isolates obtained from Western Canada.

No change has occurred in recent years with regard to the relative prevalence of the races of crown rust of oats present in Western Canada.

THE EFFECT OF THE GROWING OF RESISTANT VARIETIES ON THE YIELD OF SUSCEPTIBLE VARIETIES IN THE RUST AREA

Within the rust area of Western Canada (Manitoba and eastern Saskatchewan), the acreage seeded to rust-susceptible varieties has been negligible since resistant varieties became generally obtainable, and no dependable records are available concerning the yields of susceptible varieties in commercial fields. However, both resistant and susceptible varieties have been grown each year in experimental plots located in several places in each of the three Prairie Provinces of Western Canada.

During the 5-year period (1934 to 1938) just prior to the introduction of stem-rust resistant varieties the yield of Regent wheat in experimental plots at four stations in the rust area (Morden, Brandon, Portage la Prairie, and Gilbert Plains) exceeded the yield of the rust-susceptible variety, Marquis, by 12.1 bushels per acre. But for the 8-year period (1939 to 1946) after resistant varieties were introduced Regent out-yielded Marquis at these same four stations by only 7.2 bushels per acre. The yield differences between Marquis and Regent were statistically significant for both periods under review. As compared with the performance of Regent, the showing of Marquis during the latter period improved by some 4.9 bushels per acre. The improved showing of Marquis during this latter period was most probably due to the reduction of rust inoculum in the rust area brought about by the displacement of susceptible varieties by resistant ones.

That the differences in yield of Regent and Marquis in the rust area for the periods under review were due to the differential response of these varieties to stem-rust, rather than to any inherent difference in their yielding ability, was indicated by their yields in the areas of Western Canada where stem rust infection is usually light or absent. During the 8-year period 1939 to 1946, stem rust on Marquis and other susceptible varieties in these areas (western Saskatchewan and Alberta) was negligible. The average yields of Regent and Marquis for this period at four stations (Scott, Saskatchewan, and Lethbridge, Edmonton, and Lacombe, Alberta) were almost identical, namely, 36.6 bushels per acre for Regent and 36.8 bushels per acre for Marquis.

DISCUSSION

From the inferior yield performance of Marquis as compared with the yield of Regent in the rust area for the period since rust-resistant varieties became predominant, it may be concluded that the extensive acreage covered by resistant wheat varieties affords only partial protection to susceptible wheats in this area.

The principal sources of the air-borne stem-rust inoculum that is present in Western Canada during the summer months are susceptible varieties of wheat, oats, and barley, and certain wild grasses. With the introduction into the rust area of stem-rust resistant varieties of wheat, a notable reduction in the amount of air-borne inoculum took place. There still remains, however, an important reservoir for stem-rust inoculum in the extensive areas occupied by susceptible grasses, such as wild oats (*Avena fatua*), wild barley (*Hordeum jubatum*), *Agropyron* spp., and a number of other grasses which harbour stem rust, as well as susceptible varieties of

barley and certain varieties of oats that are resistant to some but not all of the races of stem rust present throughout the prairie region. Had these susceptible hosts not been so numerous and widely distributed throughout the rust area of Western Canada and the United States, a greater reduction in air-borne stem-rust inoculum than that indicated by the spore counts would probably have taken place following the introduction of resistant varieties.

The data presented in Table 1 show that in the period since the introduction of rust-resistant varieties in Western Canada there has been a considerable reduction in the numbers of stem-rust spores appearing in southern Manitoba in the early part of June. This is probably due to the fact that fewer spores are now being produced in the adjacent spring wheat area of the United States, where the crop consists mainly of resistant varieties. But in southwestern United States and northern Mexico, the area in which stem rust overwinters, susceptible varieties are still being grown. From this area stem rust spreads northward in the spring into the winter wheat belt of Kansas, where susceptible or partially susceptible varieties predominate. By late June the wave of stem-rust infection has extended farther north into the spring-wheat area of United States and Canada. It is apparent, therefore, that the amount of stem-rust inoculum appearing in southern Manitoba in the early part of June each year, as well as the physiologic races represented in it, are determined by the host plants present in the areas in which stem rust overwinters, and in which it develops as it spreads northward. As long as susceptible hosts are present in these areas it may be expected that stem-rust spores will continue to appear in the rust area of Western Canada and there infect susceptible cereals and grasses.

The reduction in prevalence of common physiologic races of rust due to the introduction of resistant varieties affords, by reduced competition, a greater opportunity for development and spread of virulent physiologic races that are already extant or that may be produced in nature by hybridization or mutation. That this occurs is indicated by: (1) the appearance and increase in prevalence of races such as race 128 of leaf rust of wheat following the introduction of Renown, Regent, and other wheats possessing resistance to many other races of leaf rust; (2) the increase in prevalence of races 8, 10, and 11 of stem rust of oats following the introduction of varieties, such as Vanguard and Ajax, which possess resistance to the common races of oat stem rust; (3) the appearance in Canada in 1946 of race 15B of wheat stem rust, a virulent race, first reported by Loegering and Stakman (3) in the United States in 1942.

The results of the present epidemiological study show that important changes are continually taking place in the physiologic race complex of at least some of the cereal rusts present in Western Canada. New races that are capable of attacking some of the new rust-resistant varieties have appeared, and virulent races that were quite scarce and unimportant in former years have increased in prevalence until they threaten to nullify much of the work of the plant breeders. These changes have necessitated modifications in the plant breeding programme to counteract the effects of the existing race complex. Since further changes in the race complex

of the cereal rusts may be expected to occur in the future, it will be necessary to continue epidemiological studies in Western Canada so that timely adjustments to meet these changes may be made in the breeding programme for rust resistance.

SUMMARY

1. Data obtained from spore-trap exposures, uniform rust nurseries, physiologic-race surveys, and yield tests have been analysed in an attempt to appraise the effect on the epidemiology of cereal rusts in Western Canada of introducing rust-resistant varieties of cereals in the rust area of the mid-western United States and Canada.

2. The substitution of stem-rust resistant varieties for susceptible ones has reduced the amount of stem-rust inoculum present in the air over Western Canada during the growing season, but has had no appreciable effect on the amount of air-borne leaf-rust inoculum.

3. Stem rust of wheat apparently does not now spread as far northward and westward in Western Canada as it did before resistant varieties were generally grown.

4. Since the introduction of resistant varieties, a definite change has taken place with respect to the relative prevalence of the various physiologic races of stem rust of oats and leaf rust of wheat present in the rust area. The races of these rusts that are more virulent towards the newly introduced cereal varieties have increased in prevalence. The introduction of resistant varieties has not appreciably affected the complex of the physiologic races of stem rust of wheat and crown rust of oats in Western Canada. However, a new race of stem rust, 15B, capable of infecting the varieties of wheat that are now being grown throughout the rust area, was found in one locality in Manitoba in 1946.

5. Susceptible varieties within the rust area, although afforded a certain amount of protection by the surrounding acreage of resistant varieties, are still subject to the rust hazard, as was demonstrated in yield tests.

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THE EFFECT OF FLOODING ON EMERGENCE OF FORAGE CROP SEEDS[1]

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Time of seeding is one of the major problems associated with the successful establishment of forage crops on low lying spring flooded lands in Western Canada. Depending on the length of the flooding period, it may not be possible to seed such areas until June or even early July. Seeding at this time is extremely hazardous as the following period is frequently hot and dry and, consequently, seedlings may not survive. Other seeding dates are early fall or late fall just prior to freeze-up. The latter date is most successful on areas not subjected to early spring flooding. This time of seeding would be preferable on spring flooded land providing the forage crops used were able to emerge sufficiently to produce a satisfactory stand following the flooding period.

In a previous paper[3] results were reported on the emergence of Reed canary grass seed following periods of flooding from 7 to 63 days. The data from this greenhouse experiment showed a slight decline in emergence as the length of the flooding period increased. The number of seeds that emerged following the longest flooding period was still considerable, and would be enough to result in a satisfactory stand under field conditions. The ability of Reed canary grass seed to remain viable under water for relatively long periods and emerge following drainage, prompted the authors to investigate the effect of flooding on seeds of a number of species of forage crops. The crops included have proven to be of value on low lying spring flooded land or are under test to determine their possible usefulness. The results of this investigation are presented.

METHOD

The investigation was conducted in the greenhouse. Owing to limited space, it was necessary to run two separate experiments, each including seven different species of grasses and legumes. These were as follows:

Experiment I

Trifolium hybridum L. . . . . Alsike clover
Melilotus alba Desv. . . . . Sweet clover
Medicago media Pers. . . . . Alfalfa
Phalaris arundinacea L. . . . . Reed canary grass
Bromus inermis Leyss. . . . . Bromegrass
Phleum pratense L. . . . . Timothy
Festuca elatior L. Meadow fescue

[1] Contribution from the Forage Plants Division, Experimental Farms Service, Ottawa, Canada. Presented at the annual meeting of the American Society of Agronomy, Fort Collins, Colorado, August 24-27, 1948.

[2] Assistants in Forage Plants.

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Experiment II

Trifolium pratense L. .... Altaswede red clover
Trifolium fragiferum L. .... Strawberry clover
Agropyron elongatum (Host) Beauv. .... Tall wheatgrass
Agropyron intermedium (Host) Beauv. . Intermediate wheatgrass
Agropyron trachycaulum (Link.) Malte
var. typicum Fern. .... Slender wheatgrass
Elymus virginicus L. var. submuticus
Hook. .... Virginia wild rye
Alopecurus pratensis L. .... Meadow foxtail

The first experiment started in January and concluded in April, 1947, while the second began in October, 1947 and terminated in January, 1948. The treatments in both experiments were identical. They consisted of four periods of flooding, 3, 6, 9 and 12 weeks, and a check. Germination tests were made on all seed lots prior to each experiment. One hundred seeds of each species were placed on top of two and one-half inches of dry loam soil in the bottom of gallon crocks. The seeds then were covered with an additional one-half inch of soil. Immediately after planting, all crocks excepting the checks were filled with water to a depth of six inches above the soil surface and maintained at this level until drained. The flooded crocks were drained at intervals of 3, 6, 9 and 12 weeks. The soil in the check crocks was merely kept moist enough to produce maximum emergence of the seeds. The position of the treatments was at random in each of the four replicates used, and the seven species were randomized in each treatment.

Following drainage the first emergence, if any, in each crock was noted. Subsequently, daily counts were made until such time as no further emergence occurred.

RESULTS AND DISCUSSION

The notes recorded from the two experiments showed that flooding delayed emergence as compared to the checks. Emergence in the check crocks began five to ten days after planting, but in the flooded crocks it did not begin until 16 to 20 days after draining. This delay, no doubt, was due to the water-logged condition of the soil which existed. As soon as the soil dried out sufficiently to become aerated, emergence began in those cases where flooding had not totally destroyed seed viability. By increasing the flooding period, no increase was noted in the length of time required for emergence after draining. Species which emerged after 12 weeks' flooding did not take any longer to do so than after three weeks' flooding.

The average per cent emergence of each species from each period of flooding is presented in Table 1. Per cent emergence was determined by—

$$\frac{\text{Number of seeds emerging}}{\text{Germination of the species}} \times 100$$

From an examination of the data in Table 1, it will be seen that flooding materially affected the emergence of several of the species included in the two experiments. As a group, the legume seeds were unable to endure

TABLE 1.—AVERAGE PER CENT EMERGENCE OF SEEDS FOLLOWING FLOODING

Species	Period of flooding				
	Check	3 Weeks	6 Weeks	9 Weeks	12 Weeks
Experiment I—					
Reed canary	75.0	96.4	87.1	90.3	91.1
Timothy	70.4	73.6	66.6	54.6	57.0
Bromegrass	85.5	70.0	50.9	52.1	25.7
Meadow fescue	91.9	66.6	49.1	31.7	16.9
Alsike clover	72.7	61.8	14.4	—	—
Alfalfa	71.4	53.3	—	—	—
Sweet clover	37.0	—	—	—	—
Experiment II—					
Slender wheatgrass	89.1	82.6	76.9	78.4	51.7
Virginia wild rye	77.7	48.6	57.1	47.8	38.5
Tall wheatgrass	92.2	57.8	41.2	28.9	27.1
Meadow foxtail	99.9	38.8	38.6	23.6	16.4
Intermediate wheatgrass	97.3	17.7	3.5	—	—
Strawberry clover	96.5	5.0	3.5	—	—
Altaswede red clover	89.2	2.8	—	—	—

even the shorter periods of flooding. Alsike clover and alfalfa were the two best species of those tested and both emerged fairly well after three weeks' flooding. No alfalfa emerged after six weeks' flooding, and the emergence of alsike was slight. Sweet clover, strawberry and altaswede red clover had only neligible emergence at the end of three weeks' flooding.

Seed of the grasses included in the two experiments was able to remain viable, in varying degrees, even after the longest periods of flooding. The exception among the nine grasses was intermediate wheatgrass, which had a low emergence after three weeks' flooding and practically none after six weeks. Meadow fescue and meadow foxtail both emerged at the end of the twelve-week flooding period, but their emergence was considerably reduced as compared to the checks. Meadow fescue held up better throughout than did meadow foxtail. Virginia wild rye, bromegrass and tall wheatgrass constitute a group whose seeds were able to endure rather well, even the longest flooding period. After twelve weeks' flooding, these species still emerged 38.5, 25.7 and 27.1 per cent, respectively. Virginia wild rye and bromegrass held up better throughout than tall wheatgrass, which dropped sharply in emergence following three weeks' flooding.

The outstanding species was Reed canary grass, whose seed was apparently unaffected by the length of the flooding period. Slender wheatgrass and timothy ranked next, both species emerging over 50 per cent after twelve weeks of flooding.

While the data from these two experiments indicate that seed of several forage species is able to endure long periods of flooding in the greenhouse, the practical significance of the results remains to be confirmed by field tests. Among the grasses tested, it so happens that the best six species in this respect, namely, Reed canary, slender wheatgrass, timothy, Virginia wild rye, bromegrass and tall wheatgrass, have either proven to be of considerable value for use on low lying spring-flooded lands, or are

showing promise in this respect. It is possible that late fall seeding of these species would be successful on areas that are flooded for fairly long periods in the spring.

It is unfortunate that none of the legumes tested was able to endure more than a short period of flooding as they are useful additions to forage mixtures. It would seem unlikely that higher emergence would occur in the field than in the greenhouse. However, it is possible that alsike clover and alfalfa could be seeded in mixtures in locations where the spring flood period was of relatively short duration.

SUMMARY

On spring flooded areas in Western Canada it is usually impossible to seed forage crops until June or early July. A preferable time to seed would be in the late fall just prior to freeze up, provided seed of the crops used was able to endure the spring flooding period and emerge enough thereafter to produce a satisfactory stand.

In greenhouse experiments, the relative ability of 14 species of forage crop seeds to remain viable through periods of flooding from 3 to 12 weeks was determined. Seed of the grasses was able to endure flooding better than the legumes tested. Reed canary grass seed (*Phalaris arundinacea* L.) was particularly outstanding, showing no decrease in emergence after 12 weeks of flooding. Next in order were slender wheatgrass (*Agropyron trachycaulum* (Link.) *Malte* var. *typicum* Fern.) and timothy (*Phleum pratense* L.), both emerging about equally well from all flooding periods. Seed of Virginia wild rye (*Elymus virginicus* L. var. *submuticus* Hook.), bromegrass (*Bromus inermis* Leyss.) and tall wheatgrass (*Agropyron elongatum* (Host.) Beauv.) showed good ability to endure flooding as well but ranked below timothy and slender wheatgrass. Emergence of meadow fescue (*Festuca elatior* L.) and meadow foxtail (*Alopecurus pratensis* L.) was reduced considerably by twelve weeks' flooding. The only grass seed which failed to emerge to any extent after flooding was intermediate wheatgrass (*Agropyron intermedium* (Host.) Beauv.). Although a small percentage emergence was recorded following three weeks' flooding, there was practically none after six weeks.

Of the five legumes included in the investigation, strawberry clover (*Trifolium fragiferum* L.), altaswede red clover (*Trifolium pratense* L.), sweet clover (*Melilotus alba* Desv.), alsike clover (*Trifolium hybridum* L.) and alfalfa (*Medicago media* Pers.), only seed of the latter two species was able to endure flooding but for considerably shorter periods than the grasses.

Subject to corroboration under field conditions, the results indicate several grass species might be successfully seeded in the late fall on areas flooded in the spring for long periods. Where the flooding was of short duration, alfalfa and alsike clover possibly could be included in mixtures.

A STUDY ON FIELD EXPERIMENTS OF SEMI-LATIN SQUARE DESIGN[1]

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INTRODUCTION

In 1931, "Student" (11) announced a balanced arrangement which he called "equalized randomized block", and recommended to a horticulturist that he test 10 varieties or treatments in 5 replicates with double local control as in a common latin square. The same design, as discussed by Yates (13), was put forward independently by Pitman of Tasmania under the designation "semi-latin square". Snedecor (9), in 1934, also gave a similar pattern for the use of this design in testing 16 varieties arranging into a (4 × 4) latin square with 4 varieties in each latin square plot. This design was then used quite extensively by several workers in carrying on agricultural experiments. Published results of experiments arranged as semi-latin squares include work by Pope (7) in Arkansas, Stringfield, Lewis and Pfaff (10) in Ohio, Zuber and Robinson (14) in Iowa, Riddle and Baker (8) in California and Harrington (4) in Saskatchewan.

In "Student's" original plan, the assignment of ten varieties or treatments, A to J, to the plots in the first block was random, but each successive block had its arrangement more and more controlled, so that (1) each of the five columns contained one plot only of the ten varieties and (2) varieties A, D, E, F and J occurred in the top row of the blocks three times and in the lower row twice, while for B, C, G, H, I the position was reversed. This arrangement is similar to the "split-plot latin square" in general form excepting that in the latter, the same group of varieties is used for each of that latin square plots or main plots, while for the semi-latin square, there is no such restriction. The statistical treatment for these two designs is also different. For the split-plot latin square, the design provides two estimates of error for each experiment, one for the comparison of varieties falling in the same groups and the other for the comparison of varieties falling in different groups. The first standard error is derived directly from the sub-plot error. For the second, the mean of the main-plot and sub-plot errors are weighted in the ratio 1: k, where k is the number of varieties in each group. Since in the semi-latin square the varieties are not arranged in groups in the main plots, it is impossible to divide the analysis of variance into two parts as in the split-plot latin square. Thus the resultant estimate of error is different from that of the "split-plot latin square", and may have some bias as mentioned by Yates (12, 13).

In the present study the standard error distribution of 133 field experiments of the semi-latin square arrangement was analysed for the following purposes: (1) to estimate the relative efficiency of the design compared with the randomized block design; (2) to study the nature of the bias in the estimation of error; (3) to calculate the fractional bias with actual experimental data and to suggest methods of adjusting this bias.

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RELATIVE EFFICIENCY OF SINGLE AND DOUBLE RESTRICTIONS OF THE DESIGN

The Field Husbandry Department of the University of Saskatchewan used the semi-latin square design for varietal trials as early as 1933. During the fourteen years from 1933 to 1946, out of a total of 523 experimental designs used 133 were semi-latin squares. The crop distribution of these 133 experiments was: 44 on wheat, 45 on barley, 39 on oats, 3 on rye, 1 on flax and 1 on peas. The standard errors in per cent of these experiments were classified and are presented by crops in Table 1.

The average standard error for the 133 experiments was 14.8 per cent which was about the same size as the average standard error of 133 randomized block experiments (14.6 per cent) and much larger than that of 81 experiments of lattice designs (12.0 per cent), all of which were run by the same department and reported by Ma and Harrington (6) in 1948. The semi-latin square design is so arranged that it can be considered as a common randomized block test with either rows or columns taken as blocks and the data analysed as a randomized block test with only a single restriction. An attempt was made to ascertain the relative efficiency of this design and the common randomized block arrangement. The relative efficiency has been calculated in the same manner as Yates (12) used in studying the efficiency of the latin square compared with the randomized block. Since the ranges of the percentages of efficiency were large, with a maximum as high as 1443 per cent in one case, the median value was used to express the average percentage of efficiency. The results for the different crops are given in Table 2.

The efficiency of the semi-latin square compared with the randomized block design was much greater when columns were used as blocks than when rows were used as blocks. This was expected since the bulk of the semi-latin squares were about twice as long as wide. Thus the columns (which ran lengthwise of the design) accounted for less soil variability than the rows and were a less efficient local control than the rows in a large proportion of the semi-latin squares. The semi-latin square would be expected to show greater efficiency when compared with randomized blocks using the columns (with their relative low efficiency in local control), as blocks than when compared with randomized blocks using the rows (with their relative high efficiency in local control) as blocks.

The results showed the efficiency of the semi-latin square compared with the randomized block design to be: for wheat, 189 per cent with columns used as blocks and 122 per cent with rows used as blocks; for barley, 136 per cent and 116 per cent, respectively; for oats, 186 per cent and 109 per cent; for all three crops (133 experiments) 168 per cent and 118 per cent, respectively.

A study of Table 2 also reveals that when rows were used as blocks, in a randomized block plan, 2 experiments out of 44 in wheat, 10 experiments out of 45 in barley and 15 experiments out of 39 in oats, a total of 27 experiments of a semi-latin square design out of 133 were less efficient than the randomized block. When columns were used as blocks, only 1 experiment in wheat and 1 experiment in barley, or a total of 2 out of 133 were less efficient.

TABLE 1.—DISTRIBUTION OF STANDARD ERRORS IN PER CENT OF 133 EXPERIMENTS OF SEMI-LATIN SQUARE DESIGN

S.E. in per cent	Wheat	Barley	Oats	Rye	Flax	Peas	Total
4.1— 8.0	3	6	4	—	—	—	13
8.1—12.0	12	10	14	—	—	—	36
12.1—16.0	13	11	7	2	—	1	34
16.1—20.0	10	9	8	1	1	—	29
20.1—24.0	2	3	4	—	—	—	9
24.1—28.0	2	3	1	—	—	—	6
Over 28.0	2	3	1	—	—	—	6
Total experiments	44	45	39	3	1	1	133
Average S.E.	14.6	15.3	14.0	16.4	20.0	15.7	14.8

FRACTIONAL BIAS OF THE ESTIMATED ERROR OF THE SEMI-LATIN SQUARE

Yates (12) in 1935, first criticized this design for its biased error. It was his opinion that it is only possible to make unbiased estimates of the appropriate errors when the treatments or varieties are grouped so to give the equivalent of a split-plot arrangement. Goulden (3) in reviewing the methods used for testing a large number of varieties referred to Yates' suggestion that this design suffers from a biased error and showed that the bias will usually be positive. Cox, Eckhardt and Cochran (1) and Zuber (14) also condemned the design in favour of the incomplete block designs. Riddle and Baker (8) considered that the experimental error estimates on semi-latin squares were not biased in the sense of Yates' criticism, although the method used by them for test is of doubtful validity.

As far as the writers known, there has been no detailed study made on the problems of the bias in the semi-latin square; yet such a study appears well worth-while. The problems may be enumerated as follows: (1) What direction does the bias take? Is it an under- or an over-estimation of the experimental error? (2) What is the size and what are the possible limits of the bias? (3) How may the bias be estimated from experimental data? (4) How may the bias be adjusted in actual field experimental results?

The bias in the semi-latin square arises because plots in the same group are correlated. The reason is the same as that for the main plot error usually being larger than the sub-plot error in the split-plot latin square. This can be illustrated as follows: Suppose that there are p k varieties, arranged in a $(p \times p)$ latin square with k plots or k varieties in each group. If σ^2 is the variance of an individual plot, and if plots in the same group have an intra-class correlation r, then it may be shown that the expected value of the true error mean square is equal to

$$T = \sigma^2\left(1 - \frac{(k-1)}{(pk-1)}r\right) \tag{1}$$

On the other hand, the expected value of the error mean square that is obtained from the analysis of variance of the semi-latin square is equal to

$$E = \sigma^2\left(1 - \frac{2\,(k-1)}{(pk-2)}r\right) \tag{2}$$

TABLE 2.—THE RELATIVE EFFICIENCY OF SEMI-LATIN SQUARE COMPARED TO COMMON RANDOMIZED BLOCK EXPERIMENTS

Percentage relative efficiency	Wheat		Barley		Oats		Rye		Flax		Peas		Total	
	Row*	Col †	Row	Col.	Row	Col.	Row	Col	Row	Col.	Row	Col.	Row	Col.
80–100	2	1	10	1	15	—	—	—	—	—	—	—	27	2
100–120	19	6	16	14	10	10	—	2	—	1	—	—	45	33
120–140	8	3	11	9	8	3	3	—	—	—	—	—	30	15
140–160	3	5	2	3	1	4	—	—	—	—	1	—	7	12
160–180	4	4	3	5	2	1	—	1	—	—	—	—	9	11
180–200	1	7	—	1	1	5	—	—	1	—	—	—	3	13
200–220	2	5	3	3	1	3	—	—	—	—	—	—	6	11
220–240	—	1	—	1	—	—	—	—	—	—	—	—	—	2
240–260	3	2	—	2	1	1	—	—	—	—	—	—	4	5
260–280	1	2	—	1	—	1	—	—	—	—	—	—	1	4
280–300	1	—	—	—	—	—	—	—	—	—	—	—	1	—
Over 300	—	8	—	5	—	11	—	—	—	—	—	1	—	25
Total number of experiments	44	44	45	45	39	39	3	3	1	1	1	1	133	133
Median percentage	122.5	188.6	115.6	136.4	109.0	186.0							117.6	168.2
Ranges of percentage	98.3–284.5		93.6–207.9		88.2–258.8								88.2–284.5	
Ranges of percentage		93.7–994.2		100.0–530.5		101.0–1443.1								93.6–1443.1

* The rows are used as blocks.

† The columns are used as blocks.

T is different from E, and this difference will indicate the bias in the analysis of variance error. By simplification, the fractional bias can be calculated as formula (3)

$$b = \frac{(E - T)}{T} = \frac{-\,pk\,(k-1)\,r}{(pk-2)\,[(pk-1) - (k-1)\,r]} \tag{3}$$

Since r must lie between $+1$ and $-\frac{1}{(k-1)}$, so the upper and lower limits for the fractional bias are given as:

$$\text{Lower limit (when } r = +1) = \frac{-\,p\,(k-1)}{(p-1)\,(pk-2)},$$

$$\text{Upper limit } \left(\text{when } r = \frac{-1}{(k-1)}\right) = \frac{1}{(pk-2)}$$

Under practical field conditions, r usually will be positive, so that the design gives an under-estimate of the true error, i.e. a negative fractional bias is usually obtained.

In practice, if one wishes to find out the extent of bias of a semi-latin square experiment, he should calculate or estimate from the experimental data the intra-class correlation between the plots of a group. This cannot be done from the actual semi-latin square experiments, because the varieties are different in each latin square plot, and the plot differences in one group are confounded with the varietal differences. But r can be estimated either from uniformity data, or from the results of split-plot latin square experiments. Suppose there is a split-plot latin square for testing pk varieties arranged into $(p \times p)$ latin square with k varieties per group. Then the expected values of main-plot and sub-plot errors are given as follows:

$$\text{Main-plot error } E_a = \sigma^2\,(1 + (k-1)\,r) \tag{4}$$

$$\text{Sub-plot error } E_b = \sigma^2\,(1 - r) \tag{5}$$

Therefore the intra-class correlation coefficient r can be estimated from the main and sub-plot errors actually calculated from the experimental results i.e.

$$r = \frac{E_a - E_b}{E_a + (k-1)\,E_b} \tag{6}$$

and

$$b = \frac{-\,p\,(k-1)\,(E_a - E_b)}{(pk-2)\,[(p-1)\,E_a + p\,(k-1)\,E_b]} \tag{7}$$

Instead of estimating r and b from the difference of E_a and E_b, we may simplify the calculation by using the ratio of E_a to E_b.

Let

$$a = \frac{E_a}{E_b},\ r = \frac{a-1}{a + (k-1)} \tag{8}$$

and

$$b = \frac{-\,p\,(k-1)\,(a-1)}{(pk-2)\,[(p-1)\,a + p\,(k-1)]} \tag{9}$$

APPLICATION OF FRACTIONAL BIAS FORMULA TO ACTUAL EXPERIMENTAL RESULTS

Seventeen experiments of split-plot latin square design were conducted at the University of Saskatchewan in 1936 and 1937 on wheat, barley and oats as described by Ma and Harrington (6). The number of varieties tested varied from 8 to 48. Eleven experiments were of the (4 × 4) type and the remaining were (6 × 6). It is interesting to apply the formula given above to the data of these 17 experiments in order to estimate their intra-class correlation coefficients and the fractional bias. The significance of the coefficients may be tested by means of the transformation of r to z, where $z = \frac{1}{2} \log_e \left(\frac{1 + (k - 1) r}{1 - r}\right)$ with the standard error of z equal to $\sqrt{\frac{k}{2 (k - 1) (n - 2)}}$ with n = total number of groups and k = number of plots per group. Or the significance may be tested easily by the variance ratio of E_a to E_b i.e. the F-value with degrees of freedom (p − 1) (p − 2) and p (p − 1) (k − 1), respectively. The results are given in Table 3.

Only one of the 17 experiments showed a negative correlation; in other words, the error calculated for that particular semi-latin square would be an over-estimation of the real error. But this over-estimation was so small, only 0.3 per cent, that it had no significance. On the other hand, the other 16 experiments showed positive correlations with sizes ranging from + 0.027 to + 0.828. The underestimation of error mean square ranged from 0.7 per cent to 22.3 per cent of the real error mean squares. The test of significance of these 17 coefficients by transformed z values showed 13 to be significant and for these demonstrated a real correlation between plots within the same group.

TABLE 3.—THE CORRELATION COEFFICIENTS AND FRACTIONAL BIAS PERCENTAGES OF SEVENTEEN SPLIT-PLOT LATIN SQUARE EXPERIMENTS

Crops	p	k	Number of varieties	r coefficient	Z ± S. E.	b = $\frac{(E - T)}{T} \times 100$
Barley	4	4	16	0.6016	0.9758 ± 0.2182*	−15.6
Wheat	4	8	32	0.7001	1.4903 ± 0.2020*	−20.0
Wheat	4	7	28	0.4197	0.9009 ± 0.2042*	−11.1
Wheat	4	7	28	0 7718	1.6034 ± 0.2042*	−22.3
Wheat	4	12	48	0.0270	0.1426 ± 0.1975	− 0.7
Wheat	4	7	28	−0.0116	−0 0417 ± 0.2042	+ 0.3
Wheat	4	6	24	0.1975	0.4544 ± 0.2069*	− 4.9
Wheat	4	12	48	0.2258	0.7521 ± 0.1975*	− 5.8
Wheat	4	10	40	0.3716	0.9665 ± 0.1975*	− 9.9
Oats	4	2	8	0.3965	0.4186 ± 0.2672	− 8.0
Barley	4	2	8	0.1407	0.1426 ± 0.2672	− 2.7
Wheat	6	3	18	0.2728	0.3757 ± 0.1483*	− 3.7
Wheat	6	4	24	0.8283	1.5053 ± 0.1400*	−13.2
Wheat	6	3	18	0.4403	0.6059 ± 0.1483*	− 6.1
Wheat	6	3	18	0.6909	1.0206 ± 0.1483*	−10.0
Wheat	6	3	18	0.6227	0.8917 ± 0.1483*	− 8.9
Wheat	6	3	18	0 6150	0 8781 ± 0.1483*	− 8.8

* = Significant.

Since the semi-latin square design usually underestimates the real error mean square, a method of adjusting for this negative bias is necessary. But this adjustment is only possible when the intra-class correlation between plots is obtained previously. One method of achieving this adjustment is to calculate the extent and the average value of the correlation coefficient based on accumulated actual field experimental data of split-plot latin square designs. Another method is to estimate the r value from data from uniformity trials run on land to be used for conducting the semi-latin square experiments.

Considering the first method, the average correlation coefficient of the 17 experiments of split-plot latin square design was estimated by Fisher's (2) transformed z-method. First, the average of the 17 values was obtained by weighing each z by its reciprocal of corresponding variance. Then the products were summed up and divided by the sum of weights to give the average z value, which was 0.8216. This was transformed back to r, giving + 0.4247.

To illustrate the adjustment of a semi-latin square error where the intra-class correlation is known, we can assume a (4 × 4) type for testing 24 varieties with 6 plots per group. Let us also assume that the mean and variance of such an experiment are 120 and 144, respectively, and r = + 0.4247. The fractional bias is then determined as

$$b = \frac{-4 \times 6\,(6-1) \times 0.4247}{(4 \times 6 - 2)\,[(4 \times 6 - 1) - (6-1) \times 0.4247]} = -.111 \text{ or } -11.1\%$$

The range of r of this design is from − 0.2 to + 1 thus the corresponding possible limits of the fractional biases range from + 4.5 per cent to as high as − 30.3 per cent.

The adjusted variance is calculated as follows:

$$E^1 = \frac{E}{(1+b)} = \frac{144}{(1-0.111)} = 161.98 \tag{10}$$

Where E^1 = adjusted variance and E = actual variance.

The unadjusted standard error is 12 and equal to 10 per cent of the mean, while the adjusted standard error is 12.72 or 10.6 per cent of mean.

The second method is the use of uniformity trials. Uniformity trials conducted in the field before running experiments give an idea of the association of the plots within groups and this correlation of plots reveals the heterogeneity of the soil and its suitability for experimentation. Suppose pk varieties with (p × p) latin squares and k-plots per main plot are superimposed on a uniformity trial. The partition of degrees of freedom for such an experiment is (p − 1) for rows, (p − 1) for columns, $(p-1)^2$ for error a or (E_a), p^2 (k − 1) for error b or (E_b) and (p^2k − 1) for the total. A correlation coefficient is then estimated from error (a) and error (b). Such a correlation coefficient was used by Harris in 1915 and 1920 as given in Hayes and Immer (5) for studying soil heterogeneity; he termed it the coefficient of soil heterogeneity. Harris used uniformity data obtained from several investigators and then measured, in terms of intra-class correlation, the extent to which contiguous plots resembled each other. The larger the coefficient the greater was the heterogeneity. He obtained quite significant coefficients for various crops.

TABLE 4.—VARIANCES AND CORRELATION COEFFICIENTS OF FOUR TRIALS OF LATIN SQUARES SUPERIMPOSED ON UNIFORMITY TRIALS DATA

	D.F.	First trial variances	Second trial variances	Third trial variances	Fourth trial variances
Rows	2	27.35	34.77	4.10	50.17
Columns	2	537.52	991.60	10.18	0.44
Error (a)	4	75.35	42.78	14.54	3.16
Total	8	178.90	277.98	10.84	14.37
Error (b)	27	27.92	23.90	12.15	5.95
Total	35	62.43	81.98	11.85	7.87
r		0.297	0.165	0.048	−0.133
F		2.69	1.79	1.20	1.88

Significant F for $n_1 = 4$, $n_2 = 27$. 5% F = 2.73.

Four samples of (3 × 3) latin squares with 4-plots per group for testing 12 varieties were superimposed on the potato uniformity trials reported by Kalamker and discussed by Yates (13). The correlation coefficients of these four trials are given in Table 4. None of the correlation coefficients was significant at the 5 per cent point. In this example the soil was shown to be quite homogeneous and the bias in a semi-latin square experiment conducted on such land would not be appreciable.

DISCUSSION

The main criticism of the semi-latin square design as stated by many workers is the bias in the estimated error. The detailed study of this design revealed that bias arises from the correlation of the plots within the latin square plot or main plot. This intra-class correlation may be shown to be significant or non-significant depending upon the heterogeneity of the soil in which the experiments are conducted. Also this correlation may be either positive or negative, that is, the bias may be sometimes in one direction and sometimes in the other. In most cases the real error is underestimated.

Where it is desired to use this design in field test of varieties, the bias should be adjusted by first estimating the correlation coefficient either from the previous data of the split-plot latin squares or from uniformity trials, and then applying the formulae as given above. With either method the adjustment is completely dependent upon the accuracy of the correlation value secured. The actual results of 17 split-plot latin square experiments, as given in Table 3, show a wide variation of the obtained correlation coefficients, the values ranging from − 0.01 to + 0.83. So it is of doubtful value to make use of such an average correlation coefficient secured from previous uniformity trials or split-plot experiments for adjusting the subsequent experiments. Moreover, the writers feel that a wide range of correlation coefficients may be expected under variable soil-climatic conditions such as obtain in Central Saskatchewan. Furthermore,

even if an accurate correlation coefficient is obtainable for adjustment, the land and labour devoted to carrying out the uniformity trial or split-plot latin square experiments would also reduce the efficiency of the semi-latin square design. The bias may be left out of consideration if fairly homogeneous land is used for a test. However, if the soil is uniform the argument for using a semi-latin square loses its value.

As compared to the randomized block arrangement, the semi-latin square design allows the varieties tested to be distributed more evenly throughout the field. Also, by having each variety appear only once in each row and once in each column, more variation due to soil heterogeneity may be eliminated from the estimated error in the analysis of variance. This is demonstrated very clearly in the present study of the efficiency of the semi-latin square design compared to that of the randomized block for 133 actual field experiments. However, the writers (6) have shown that when the number of varieties is not very large, say under 10, the semi-latin square design, regardless of bias, may be considered less satisfactory than the latin square, and for tests of a larger number of varieties, is distinctly inferior to the lattices.

The importance of the comparison of the efficiency of the semi-latin square with that of the lattice designs appears to warrant a somewhat detailed discussion here. In the earlier paper of the writers (6) they reported on the investigation of the distribution of the percentage standard errors of 523 field experiments of different designs conducted by the Field Husbandry Department of the University of Saskatchewan, and found the distribution of the average standard error in per cent of the semi-latin square and of the lattice according to the number of varieties used was as follows:

Number of varieties per test	Below 11	11–20	21–40	Above 40
Semi-latin square	10.98 (10)*	14.15 (51)	15 48 (64)	17.93 (8)
Lattice	—	10 36 (10)	12.12 (53)	12.60 (18)

* The number within the bracket indicates the number of tests.

For the semi-latin square, the average standard error in per cent increased rapidly when the number of varieties per test increased. The average standard error of each class for number of varieties was larger for the semi-latin square than for the lattice in every corresponding class and the difference was largest when the number of varieties per test was above 40. The efficiency of the semi-latin square compared with the lattice was calculated for each class. For the class with 11-20 varieties, the semi-latin square was only 54 per cent as efficient as the lattice; for the 21-40 class the relative efficiency was 61 per cent and for the above 40 class the semi-latin square was only 49 per cent as efficient as the lattice. While these results do not show a trend toward a reduction in the efficiency of the semi-latin square with increased number of varieties, it is well known that such

a trend may be expected. Even without considering the biased estimate of the experimental error, the semi-latin square is shown by these results to be far inferior to the lattices for testing a moderate or large number of varieties.

SUMMARY AND CONCLUSIONS

1. The data from 133 field experiments designed as semi-latin square and conducted by the Field Husbandry Department of the University of Saskatchewan during the years 1933 to 1946 were used to study the efficiency of the semi-latin square in relation to the common randomized block design.

2. It was found that when rows were taken as blocks, to simulate a randomized block design, the semi-latin square was 18 per cent more efficient than the randomized block. When columns were used as blocks the semi-latin square was 68 per cent more efficient than the randomized block.

3. The semi-latin square design shows a bias in the estimated error, the bias arising from plots in the same main plot or group being correlated. Formulae for estimating this bias are derived with possible lower and upper limits. The bias may be positive or negative and may be significant or non-significant depending upon the soil heterogeneity.

4. The intra-class correlation coefficient of the plots of the same group can be estimated from uniformity data or from the experimental results of the split-plot latin square but cannot be estimated from actual semi-latin square experiments. Seventeen field experiments designed as split-plot latin squares were used to estimate this correlation. Excepting for one experiment which showed a non-significant negative correlation, the other sixteen showed coefficients varying from + 0.03 to + 0.83. Thirteen out of 16 of these positive coefficients proved significant. The under-estimation of the error mean squares ranged from 0.7 per cent to 22.3 per cent. The average correlation coefficient was calculated by means of transformed Z-values and was found to be + 0.4247.

5. Four samples of (3 × 3) latin square for testing 12 varieties were superimposed on potato uniformity data. The correlation coefficients found were + 0.297, + 0.165, + 0.048 and − 0.133, respectively. None appeared to be significant by the F-test, which indicated that the bias may not be important in reasonably uniform soil.

6. The semi latin square design has but little practical use for testing a large number of varieties not because of its biased estimate of experimental error, which might be adjusted, but because of its low efficiency in accuracy as compared to the lattice design.

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BOOK REVIEW

PRACTICAL PLANT ANATOMY, by A. S. Foster. 2nd Edition. D. Van Nostrand Co. (Canada) Ltd., 228 Bloor Street West, Toronto, Canada. 224 pages. 1949. $3.25.

This compact volume is completely rewritten and extended to include the advances made in comparative and developmental anatomy since the first edition was published in 1942. Intended for use in the laboratory, it combines the functions of a source book and a manual of laboratory directions. With a minimum of discussion, the author attempts to guide the student in his reading and laboratory study. The organization of chapters follows the pattern: the cell, cell types, tissues, tissue systems, and organs. For each topic an introduction provides descriptions, a concise historical review, and a summary of the present status of knowledge of the subject. The laboratory directions, which follow the introduction, are divided into "Materials for Study" and "Suggested Drawings and Notes". The use of living material is encouraged. Descriptive materials are combined with suggestions directing attention to features that the student is expected to work out. Diagrams and notes are recommended in partial substitution for tedious drawings of complex tissues. Each chapter concludes with a list of references. Fundamentals are stressed throughout with less attention to variations in given cells and tissues. While the absence of all illustrations detracts from the usefulness of this test as a source book, the plan should promote independent study on the part of the student.

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THE SIGNIFICANCE OF THE BACTERIAL FLORA ON WHEAT SEED IN INOCULATION STUDIES WITH HELMINTHOSPORIUM SATIVUM[1]

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INTRODUCTION

In a recent paper, Simmonds (1) brought out the importance of antibiotic organisms in tests of resistance to common root rot in cereals. His studies laid the basis for a simple technique for measuring resistance to *Helminthosporium sativum* P. K. and B. in wheat seedlings. The present paper supplies further data in support of his interpretations. It also records studies on the effect of removing and re-applying bacteria to wheat seed. Some attention is given to the effects, when seed is treated, of the disinfectants on seedlings and their effectiveness in eliminating bacteria from seed. Pertinent literature has been reviewed by Simmonds (1).

EXPERIMENTAL METHODS

In most of the laboratory tests, seedlings were grown in Petri dishes on moist filter paper. Inoculations, unless otherwise indicated, were made by application of a drop of conidial suspension of *H. sativum* to each seed. Glass rods of 3 mm. diameter, and rounded at the ends, were used to apply the suspension. Treatment methods, both as applied to seed disinfectants and antibiotic agents, have varied; they will be described as the need arises. Formalin (commercial preparation of formaldehyde, 37 per cent, in water) was used in many of the tests; wherever it was used, the seed was thoroughly washed afterwards in sterile water. Examination of the seedlings was carried out usually after four days of incubation at 24° C. Plants were placed in the following classes: free from lesions, and with slight, moderate, or severe lesions. Disease ratings were computed on a percentage basis, with values of 0, 1, 5, and 10 assigned to these classes, respectively.

SURFACE DISINFECTION OF SEED IN INOCULATION STUDIES

Simmonds reported (1) that higher disease ratings resulted from inoculation with *H. sativum* after wheat seed was treated with formalin and washed with sterile water than when not treated. Increases in lesions were ascribed to removal of bacteria antagonistic to *H. sativum*. It is

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well known that formalin-treated seed will sometimes show injury, as evidenced by lowered vigour and increased susceptibility to disease. The increased lesioning (1) might be attributed to the formalin injury rendering the seedling more liable to infection by *H. sativum*. Therefore, information was necessary to decide this point since, if the observed increases in disease following seed disinfection were due simply to seedling injury, the role of bacteria would be in doubt. A number of tests were conducted, some of which are reported below. They provide data on other aspects of the problem than the one relating to removal of bacterial seed flora.

At the outset, comparisons between formalin treated and hot-water treated grain were made. The seeds were inoculated after treatment and disease ratings were obtained. In general, when the surface flora was reduced with hot water, the disease ratings were comparable to those obtained when formalin was used. A refinement of technique was based on the premise that, if hot water was used to remove the surface bacteria, subsequent treatment with formalin should not cause any further increase in disease, provided the role of the seed treatment was simply reduction or elimination of the bacterial flora. Accordingly, a number of tests were conducted, of which one soil test and two Petri-dish tests comparing these treatments are reported.

Soil Test

Sixteen pots were filled with soil and eight of them were steam sterilized. Seed of the variety Thatcher was soaked in water at 52° C. for ten minutes. Half of this seed was then further treated for ten minutes with formalin and finally washed in sterile water. The formalin solution was made up of one part formalin in 320 parts of water. The various lots of seed were inoculated by dipping them in a conidial suspension of *H. sativum*. One-half of the pots were planted with hot-water treated seed and one-half with seed which had received both treatments. Fifty seeds were placed in each pot. After four weeks in the greenhouse at a temperature of about 70° F., the seedlings were harvested and disease ratings obtained. These are shown in Table 1.

TABLE 1.—THE INFLUENCE OF HOT WATER AND FORMALIN TREATMENTS OF THE SEED ON DISEASE RATINGS OF WHEAT SEEDLINGS INOCULATED WITH *H. sativum* IN SOIL

Treatments	Unsterilized soil	Sterilized soil
Hot water	59	68
Hot water + formalin	64	65

This test provides evidence that formalin did not induce an increase in lesioning above that ascribable to hot water alone. The differences between the two treatments in either sterilized or unsterilized soil do not approach significance.

Petri-dish Tests

Duplicate Petri-dish tests were made to further elucidate this point. Four factor factorial designs were used. Thatcher and Reward were the varieties selected and portions of each were treated as follows:

(1) Hot water, 10 minutes at 48° C. after a 20 minute pre-soak in cool water.

(2) Formalin, 20 minutes in solution of 1 : 400 concentration after a 10 minute pre-soak.

(3) Combined treatment in which formalin followed hot water.

(4) No treatment.

In addition to an inoculated series, a duplicate uninoculated series was included to determine whether any of the treatments caused delay in germination or other abnormalities. Scrutiny of the uninoculated plates after four days' development showed no apparent differences in germination and practically no lesioning; therefore, only the results of the inoculated series are reported. The disease ratings in percentage are shown in Table 2.

TABLE 2.—DISEASE RATINGS IN A PETRI-DISH TEST WITH THATCHER AND REWARD TREATED WITH HOT WATER, FORMALIN, AND THE TWO COMBINED, FOLLOWED BY INOCULATION WITH *H. sativum*

Variety	Test	Untreated	Hot water	Formalin	Hot water and formalin
Thatcher	1	29	63	59	69
	2	15	49	42	62
Reward	1	90	89	94	95
	2	91	83	95	88
Treatment means		56	71	72	78

Table 2 shows no appreciable difference in disease rating between hot water treated and formalin treated seed, thus confirming preliminary results. Furthermore, in determining the most suitable schedule to follow in formalin and hot water treatments, treated but uninoculated seeds were placed on potato dextrose agar and examined after a day or two for bacterial colonies. It appeared that treatment with water at 48° C. for 10 minutes was about as effective as formalin 1 : 400 for 20 minutes in reducing the surface flora of the seeds. Neither treatment sterilized the seed surface completely. Thatcher showed a slightly higher disease rating in the combined treatment than in either of the treatments singly, which result may have been due to more complete elimination of surface inhabiting bacteria. Reward was much more severely diseased than Thatcher. This finding is in line with numerous previous tests.

In Thatcher, the wide difference in disease rating between treated and untreated seed reflects the effect of the normal seed flora on *H. sativum*. Fairly wide differences have almost always been observed with Thatcher

and with most other varieties and lines of wheat. These differences may be further widened by incubation of the seed prior to inoculation, to increase the bacterial flora, or by bacterization.

For some reason, the Reward seedlings in this test and other Reward samples as well have not had much protection from their surface flora. Further work is required to determine whether the difference between Reward and other varieties is in type or relative abundance of bacteria carried. Numerous factors may influence abundance and the type of flora which a given variety will support.

The foregoing data appear to provide good evidence that the effect of formalin in increasing the disease incidence is due simply to partial elimination of the bacterial flora from the seed surface and not to chemical injury.

BACTERIZATION IN INOCULATION STUDIES

Another approach to the problem of whether formalin caused disease increases through injury is based on re-application of a bacterial flora to formalin treated seed. Two laboratory tests were carried on in Petri dishes and two greenhouse tests in sterile and two in unsterile soil.

Petri-dish Tests

Separate 40 gm. lots of Thatcher and of Reward seed were moistened with water equal to 50 per cent of their weight. They were incubated for 20 hours at room temperature. Suspensions of the surface organisms were made by adding 10 cc. of water to each lot, then shaking and pouring off the liquid. These suspensions were applied, both singly and combined, to the untreated and the formalin treated seed of each variety. Where the two suspensions were combined on the same seed sample, they were mixed in equal amounts and the seed dipped in them. Where one suspension was applied, it was diluted with an equal quantity of water. The result was that approximately twice as many bacteria were added to the seed in the combined as in the single treatment. The usual inoculation with *H. sativum* was carried out and the disease ratings were taken after a four-day period. Data from the uninoculated series are not included since they did not indicate abnormalities due to the various treatments. Table 3 gives the averaged data from two Petri-dish tests.

TABLE 3.—EFFECT OF BACTERIZATION ON DISEASE RATINGS IN SEEDLINGS OF THATCHER AND REWARD INOCULATED WITH *H. sativum*

Treatments*	Thatcher		Reward	
	No formalin	Formalin	No formalin	Formalin
o	33	60	80	87
r	1	5	13	22
t	6	31	12	50
rt	1	2	17	22

* r – Suspension of organisms from incubated Reward seed.
t – Suspension of organisms from incubated Thatcher seed.

The disease ratings of Table 3 have been summarized to show significant main effects and first order interactions. These are shown in the following 2 × 2 tables.

TABLE 4.—EFFECT OF SEED TREATMENT WITH FORMALIN ON DISEASE RATINGS IN REWARD AND THATCHER

	No formalin	Formalin	Means*
Reward	30	45	37
Thatcher	10	24	17
Means*	20	34	27

* Main effects exceed the 1 per cent level of significance.

TABLE 5.—EFFECT ON DISEASE RATINGS OF APPLYING BACTERIA OBTAINED FROM REWARD AND THATCHER TO THESE VARIETIES

	No Reward organisms	Reward organisms	Means*
No Thatcher organisms	65	10	37
Thatcher organisms	25	10	17
Means*	45	10	27

* Main effects exceed the 1 per cent level of significance, as also does their interaction

The usual wide difference between Reward and Thatcher in disease rating is apparent in these tests. The marked increase in disease following treatment of Thatcher with formalin constitutes evidence of a natural flora antibioltic to *H. sativum.* Reward on the other hand derived very little protection from its normal seed flora (Tables 2 and 3). Bacterization, however, decreased markedly the disease rating in Reward. It is interesting, furthermore, that the bacteria derived from the incubated Reward were as effective as those obtained from Thatcher (Table 5), yet the same seed sample from which these were obtained, when inoculated directly, was not afforded any protection. This result suggests that the bacterial flora on this sample of Reward was similar to that on Thatcher in type but so low in numbers as to require increasing before it could be effective.

Sterile-soil Tests

Two greenhouse tests in sterilized soil included treatments similar to those carried on in Petri dishes, as described above. Water suspensions of organisms obtained by incubating moistened Reward and Marquis seed were used in bacterization of the seed. A factorial design with four factors at two levels each was used in both experiments. The factors were, respectively: (1) variety of host plant, Thatcher and Reward; (2) bacterization with Reward organisms and no Reward organisms; (3) bacterization with Thatcher organisms and no Thatcher organisms; and (4) formalin treatment of the seed and no such treatment. All seed was inoculated with *H. sativum* after the above treatments were made. The third order interaction was confounded. Each test consisted of 32 five-inch pots, and 50 seeds were planted in each. After ten days of development at a temperature of about 70° F., the seedlings were removed from the soil and were

classified as to degree of lesioning. The significant main and interaction effects are shown in Tables 6 and 7. The disease ratings are averaged over two varieties, Thatcher and Reward.

TABLE 6.—DISEASE RATINGS, IN AN INOCULATION TEST WITH *H. sativum* IN STERILE SOIL, SHOWING THE INFLUENCE OF BACTERIZATION WITH THATCHER AND REWARD ORGANISMS AND THEIR INTERACTIONS

	No Reward organisms	Reward organisms	Means*
No Thatcher organisms	63	39	51
Thatcher organisms	43	39	41
Means*	53	39	46

* Necessary difference for significance in means at the 1 per cent level is 9.

Bacterization of the seed with organisms from both Reward and Thatcher, singly and in combination, reduced significantly the disease ratings on wheat seedlings caused by *H. sativum*. There was, however, a highly significant interaction between the two treatments, indicating that their effects on the disease ratings were not additive.

TABLE 7.—DISEASE RATINGS SHOWING THE EFFECT OF FORMALIN TREATMENT OF THE SEED AND THE INTERACTION BETWEEN FORMALIN SEED TREATMENT AND BACTERIZATION OF THE SEED WITH THATCHER ORGANISMS

	No Thatcher organisms	Thatcher organisms	Means*
No formalin	67	40	53
Formalin	76	48	62
Means*	71	44	57

* Necessary difference for significance in means at the 5 per cent level is 9; at the 1 per cent level is 12.

It is evident from Table 7 that bacterization was very effective in reducing the incidence of disease, while formalin treatment increased the disease rating significantly. The seedlings showing the lowest amount of disease were those which had not been treated with formalin but had been bacterized. The ones in which the seed had been treated with formalin and not bacterized were the most severely diseased.

Unsterile-soil Tests

Two tests similar in general detail to those reported above in sterile soil were carried out in unsterile soil in a bed in the greenhouse. Reward and Thatcher seed was used, one-half of each sample being treated with formalin and then washed repeatedly with sterile water. The treated and untreated portions of each sample were bacterized with (*a*) a bacterial suspension obtained by rinsing the organisms off a sample of Marquis wheat which had been incubated for 24 hours, and (*b*) a suspension of a

bacterial culture obtained from wheat seed and increased on potato dextrose agar. In addition to bacterization with each suspension singly, the two were combined on the appropriate seed samples. The test was set up as a 2^4 factorial experiment with the third order interaction confounded. Disease ratings were obtained after ten days of development in the greenhouse at around 70° F. The results from the two tests conducted at different times were quite comparable so that the results of one test only are reported here.

The usual wide differences between Reward and Thatcher as to susceptibility were observed. However, this test is reported mainly to show the effect of bacterization of seed on disease rating in an inoculation test in unsterile soil. The data are presented in Table 8 to show main and interaction effects of the two bacterial suspensions on disease ratings, average of Thatcher and Reward.

TABLE 8.—MAIN AND INTERACTION EFFECTS OF BACTERIAL SUSPENSIONS ON DISEASE RATING IN WHEAT

	No bacteria	Bacteria	Means
No treatment	31	9	20
Marquis organisms	11	5	8
Means	21	7	14

Table 8 shows a disease rating of 31 in the absence of bacterization. Each of the suspensions used in bacterization gave good decreases in disease ratings. The combined suspensions likewise gave good control though it appears their effects were not additive; either one singly was nearly as effective as the two together, and this in spite of the fact that there were approximately twice as many bacteria applied to the seed in the combined as in the single suspensions.

ARTIFICIAL WEATHERING OF MATURE WHEAT PLANTS

Perhaps the most direct evidence pointing to the effect of surface-borne bacteria in lessening the disease caused by *H. sativum* in inoculation tests with wheat and also the effect of formalin in increasing the disease rating was derived from the following test. Thirty-six pots of Thatcher wheat were grown to maturity in the greenhouse. Care was taken to avoid wetting the heads at any time and in general the air humidity was very low. A week or two after the grain was ripe the pots were divided into four groups and three of these were subjected to periods of one, two, and three days, respectively, of humid conditions. This was done by placing the plants in a moist chamber equipped with a fog nozzle which was allowed to operate intermittently. The fourth group was left untreated. A month later, 200 seeds were taken at random from each group of plants and one-half of them were treated with formalin. The seeds, treated and untreated, were then set up in a Petri-dish test and inoculated with *H. sativum*. Disease ratings were taken after four days. This test was repeated three months later with seed freshly harvested from the same

sources as the previous test. In the interim, the heads had been stored in envelopes at room temperature. The data from the two tests were analysed together. The disease ratings, averaged over the two tests, are shown in Table 9.

TABLE 9.—INOCULATION TEST WITH *H. sativum* SHOWING DISEASE RATINGS OF SEEDLINGS FROM GREENHOUSE GROWN THATCHER WHEAT, PORTIONS OF WHICH HAD BEEN EXPOSED TO HUMID CONDITIONS FOR VARYING PERIODS

Days of weathering	No formalin	Formalin
0	69	63
1	59	71
2	67	77
3	25	73

Necessary difference for significance at the 1 per cent level is 13.

In Table 9, the disease ratings of seedlings from seed which was not treated with formalin show that the 3-day period of weathering was very effective in reducing the amount of disease. The 1- and 2-day treatments did not have a highly significant effect. Formalin treatment destroyed the apparent resistance resulting from weathering. Previous work (Tables 5, 6, and 7) indicated that similar resistance was the result of an increased bacterial flora. Accordingly, 50 seeds from each of the 0-, 1-, and 3-day treatments were placed in test tubes and covered with sterile water. After five or six hours, the liquid in the tube containing the seed weathered for three days was turbid, while the other two were clear. Smears showed the turbidity to be due to bacteria. Furthermore, dry seeds of each treatment were placed on potato dextrose agar. After 24 hours, vigorous bacterial colonies had developed from every seed of the 3-day treatment, and only tiny colonies from a few seeds of the other treatments. The test demonstrates the role of bacteria in resistance of wheat seedlings to *H. sativum* and also that the effect of formalin is simply the elimination of bacteria.

DISCUSSION

Generally speaking, in inoculation tests of wheat with *H. sativum*, the results of formalin treatment and of bacterization of the seed followed the same trend in soil as in Petri dishes. There were differences, however, which were not unexpected. The role of seed disinfection in these tests was to eliminate the natural seed flora before inoculation with *H. sativum*, thus allowing the pathogen to develop without interference. In tests with unsterile soil, of course, the soil flora had an effect on the pathogen, so that the disease rating was not so high as was the case in sterilized soil or in Petri dishes. Several tests in unsterile soil did not show significantly higher disease on seedlings grown from formalin-treated than from untreated seed. On the other hand, in nearly all cases where the seedlings were grown in a more or less sterile medium, the disinfected seed produced

seedlings with a significantly higher incidence of disease. Numerous tests indicated that, with seed carrying a normal flora, there was a relationship between the effectiveness of seed treatment and the increase in disease rating of the treated over the untreated seed. Moreover, in a given variety, and with an efficient seed disinfectant, the difference in disease rating of seedlings from untreated and treated seed appeared to be an index of the relative abundance of the normal seed flora. Some seed samples gave a much increased rating following treatment. These, in all probability had an abundant natural flora. Conversely, seed produced in the greenhouse had a sparse bacterial population and, in inoculation tests, the seedlings from it had a high disease rating. In this case, treatment with formalin did not significantly change the disease rating. Artificial weathering of such seed increased the bacterial population greatly and, at the same time, rendered the seedlings much more resistant to *H. sativum.* Treatment of the weathered seed with formalin reduced its apparent resistance to *H. sativum* to the same level as before weathering.

While disinfection of the seed is essential to a seedling test of inherent resistance to *H. sativum*, there may be a place for increasing the abundance and effectiveness of the natural flora in protecting seedlings from infection. Thus, weathering which ordinarily occurs in the field probably has value. Simply moistening a seed lot and allowing it to incubate for a period of 16 hours or more will cause a great increase in its bacterial population. In turn, this results in a much reduced incidence of disease in inoculation tests. The initial seed flora has a bearing on how abundant it will be after a period of incubation. Bacterization of the seed with a suitable species of bacteria may be effective also in reducing the disease rating in inoculation tests. This procedure has given good results in inoculation tests with unsterilized as well as with sterilized soil in the greenhouse and in Petri-dish tests in the laboratory.

The treatment of wheat seed with formalin, as in the work reported in this paper, does not eliminate all the organisms present; however, it does reduce their numbers. Increasing the concentration of the fungicide or the length of treatment may result in injury to the seed and seedling. Further testing of materials is being continued in conjunction with the general problem and some of these appear promising.

SUMMARY

Treatment of seed with formalin prior to inoculation with *Helminthosporium sativum* as compared with untreated seed resulted in increased lesioning, particularly if the seedlings were grown in sterile soil or on other sterile media.

Numerous tests demonstrated that the cause of the increased disease under such conditions was the removal of surface organisms, particularly bacteria, which otherwise would have interfered with the development of the pathogen.

Different samples of wheat of a given variety may vary appreciably in the abundance of their surface flora. In inoculation tests to determine relative resistance to *H. sativum*, this variability of the seed flora results in corresponding variations in disease ratings. However, by proper surface disinfection of the seed prior to inoculation a truer measure of basic resistance of the variety is achieved. Likewise within any pure line more uniformity of results will be achieved.

The surface flora of wheat seed may be increased greatly by moistening the seed with water and allowing it to incubate for a period. Seedlings from seed so treated will show more resistance to *H. sativum* in inoculation tests, particularly in Petri dishes or in sterile soil, than those from unincubated seed. Similar results may be achieved by applying a suitable bacterial suspension to the seed prior to inoculation. In an inoculation test with *H. sativum* following bacterization of the seed, greenhouse trials indicated reduced disease in seedlings grown for ten days in unsterilized soil.

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DIGESTIBILITY STUDIES WITH RUMINANTS

XIII. THE EFFECT OF THE PLANE OF NUTRITION ON THE DIGESTIBILITY OF LINSEED OIL MEAL[1]

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In previous publications (3, 4), the effect of the level of feeding on the digestibilities of rations of hay and of hay plus linseed oil meal have been reported. The hay was fed to steers at five levels from 2.5 to approximately 9 kilograms per day. The latter quantity depended upon the capacity of the animal. The coefficients of digestibility of the various nutrients of the hay were not affected by the level of feeding. In the hay-linseed oil meal rations the feeds were fed in equal proportions. The levels of feeding of the total ration were from 2 to approximately 10 kilograms. The latter amount depended upon the capacity of the animal. The average weight of all rations at the highest level was 9.58 kilograms. It was found that the digestibility of neither the protein nor of the fat was affected by the level of feeding. On the other hand, the carbohydrate fraction showed a decrease in digestibility as the level of feeding was increased. The magnitude was not very great, amounting over the whole range of feeding to a total of approximately 4 absolute per cent. This decrease was reflected in the digestibility of the dry matter and organic matter and in the total digestible nutrients. The most marked drop was found in the digestibility of the so-called crude fibre fraction.

In the above mentioned experiment the quantity of hay was increased equally with the oil meal. Since the plane of nutrition had no effect on the digestibility of hay alone any possible effects on the digestibility of the oil cake meal might have been partially masked. To investigate this, increasing quantities of oil meal were fed with a constant ration of hay. The digestibility of the nutrients of the oil meal were calculated from the different rations and the results are reported in this paper.

For the digestion trials six grade Shorthorn steers, numbered 11 to 16, inclusive, were used. They were 1½ to 2 years old with a mean live weight during the experiment of 440 kilograms.

Six rations were fed, one of hay alone and five of various mixtures of hay and linseed oil meal. The hay was fed alone at a level of 6.5 to 7.0 kilograms per animal per day and in the mixtures at a level of 3.0 kilograms. The oil meal in the mixtures was fed at levels of 1, 2, 3, 4 and approximately 5 kilograms. The latter quantity depended upon the capacity of the animal.

The hay was largely timothy. Its botanical analysis is shown in Table 1.

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TABLE 1.—BOTANICAL ANALYSIS OF HAY

Herbage	Per cent
Timothy	65.7
Legumes (red and alsike clover, alfalfa)	33.4
Couch grass	0.7
Shepherd's purse, Canada thistle, Kentucky blue grass	Trace

The linseed oil meal was prepared by the screw-press method. The chemical composition of both feeds is given in Table 2.

TABLE 2.—CHEMICAL COMPOSITION OF FEEDING STUFFS (MEANS OF SIX VALUES)

Feeding stuff	Original dry matter	Chemical composition of dry matter				
		Ash	Protein*	Ether extract	Crude fibre	N-free extract
	%	%	%	%	%	%
Hay	86 87	5 63	9 64	1 16	39 14	44 44
Oil meal	92 69	5 45	35 66	7 56	9 47	41.86

* Protein factors (Jones (2))—Hay, 6.25 × N.
—Linseed oil meal, 5.83 × N.

The six rations were fed to the six animals through six periods in a randomized Latin square set-up. This is shown in the Appendix (Tables 6 and 7). Each period consisted of a preliminary sub-period of 16 days and a collection sub-period of 12 days. During the experiment mineral supplements of iodized salt, calcium, phosphorus, iron, copper, cobalt and manganese and vitamin supplements of A, D, E, thiamin, riboflavin and niacin were given.

RESULTS

The progress of the experiment was satisfactory with two exceptions. In periods 3 and 6 the animals receiving hay alone, namely, animal 14 in period 3 and animal 11 in period 6, had feed refusals and irregular consumption. These results were discarded. In addition, in period 2, with animal 16, the preliminary sub-period had to be lengthened thus reducing the collection sub-period to 10 days. With animal 11 in period 5 likewise the preliminary sub-period had to be lengthened, reducing the collection sub-period to 6 days. In both cases lengthening the sub-period was necessary because of adjustment of the ration during the first days of that sub-period. The remaining digestion trials progressed as scheduled.

In the Appendix (Tables 8, 9, 10 and 11), the coefficients of digestibility of the different nutrients in the rations, TDN in the dry matter of these rations and the data for the dry matter and nitrogen tabulated in the form of a Latin square, have been listed. The results for the dry matter and nitrogen have been summarized in Table 3.

The mean coefficients have been arranged both by periods and by animals with the respective ranges of variation and F values. Since there were two missing values the analysis of variance was made by first arranging

TABLE 3.—MEAN COEFFICIENTS OF DIGESTIBILITY OF DRY MATTER AND NITROGEN OF TOTAL RATIONS ARRANGED BY PERIODS AND BY ANIMALS. (MISSING VALUES INCLUDED IN MEANS, MEANS BASED ON SIX VALUES)

Coefficients of digestibility of dry matter arranged by periods and by animals				Coefficients of digestibility of nitrogen arranged by periods and by animals			
Periods		Animals		Periods		Animals	
Period No.	Coeff. %	Animal No.	Coeff. %	Period No.	Coeff. %	Animal No.	Coeff. %
1	65.2	11	65.5	1	75.8	11	75.8
2	65.0	12	65.4	2	77.0	12	76.2
3	65.0	13	63.7	3	76.0	13	75.6
4	64.6	14	65.4	4	75.4	14	76.8
5	64.7	15	64.5	5	75.3	15	74.2
6	65.2	16	65.5	6	76.3	16	77.4
Range	0.6	Range	1.8	Range	1.7	Range	3.2
F. values*	†	F. values*	5.24	F. value*	†	F. value*	1.69

* At P = 0.05, nec. F = 2.07.
† Variance for period less than error variance.

TABLE 4.—MEAN COEFFICIENTS OF DIGESTIBILITY OF OIL CAKE MEAL CALCULATED FROM MIXED RATIONS WITH HAY ARRANGED BY LEVELS OF OIL CAKE MEAL. (COEFFICIENTS IN PER CENT, MEANS OF SIX VALUES)

Level of oil cake Kg.	Coefficients of digestibility of different nutrients in per cent							T.D.N. in per cent of dry matter
	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	Total carbo-hydrates	
1	80.0	82.8	86.3	95.8	54.8	84.1	79.1	93.2
2	77.3	80.0	87.3	96.8	37.0	82.4	74 3	91.4
3	77.8	80.2	87.0	95.4	36.4	83.0	74.7	91.1
4	76.4	78.6	87.4	96.4	33.9	80.9	72.4	90.3
5*	76.0	78.3	87.2	96.0	25.4	81.5	71.3	90.4
Range	4.0	4.5	1.1	1.4	‡	3.2	7.8	2.9
F†	5.63	6.35	§	§	‡	§	5.48	§
Nec. diff.	2.0	2.1	§	§	‡	§	3.8	§

* Approx. 5 Kgs. according to capacity of animal.
† Nec. F at P of 0.05 = 2.87.
‡ Error too great for statistical analysis.
§ Differences between rations not statistically significant.

the data according to rations and periods and then by arranging them according to rations and animals. The missing plot technique of Yates was used (5).

It is evident that there were no significant differences in the coefficients of digestibility of dry matter and nitrogen between the six periods nor for the nitrogen between the six animals. In the case of the dry matter, the mean for animal 13 was slightly lower than the rest. There were no significant differences between the other five.

The coefficients of digestibility of linseed oil meal in the 5 mixed rations with hay were calculated by differences from the values of hay determined alone and the values of the total rations. These have been arranged by animals and levels of feeding in the Appendix, accompanied by an analysis of variance (Tables 12 and 13). The data are summarized in Table 4.

It will be observed that the digestibility of the nitrogen and ether extract remained constant throughout the entire range of feeding. The digestibility of the total carbohydrates showed a progressive decrease from the lowest to the highest level. This was statistically significant. The values at the lowest level were higher than the other four. The differences between these latter were not statistically significant, although there was a slight progressive decrease in digestibility with increasing levels. The results with the dry matter and organic matter were similar. While the digestibility of the nitrogen free extract and the total digestible nutrients also decreased as the level was increased the differences were not statistically significant. With the so-called crude fibre fraction the error was too large to justify a statistical analysis. It is of some significance, however, that the digestibility of this fraction was quite high at the lowest level, and showed the greatest decrease of all nutrients as the level of feeding reached the highest level.

In this experiment, therefore, it may be concluded that the level of feeding had no influence on the digestibility of the nitrogen nor on the ether extract. It did cause a moderate change in the digestibility of the carbohydrate fraction, particularly the crude fibre fraction. This change was inversely proportional to the level of feeding. It may be estimated that over the whole range there was a loss in total digestible nutrients of from 2 to 3 per cent. This finding confirms those of the previous publication (3).

TABLE 5.—PLANE OF NUTRITION OF RATIONS EXPRESSED IN TERMS OF MAINTENANCE ACCORDING TO BRODY'S STANDARDS (MEAN VALUES FOR EACH RATION BASED ON MEAN LIVE WEIGHTS OF ANIMALS FOR SIX PERIODS FOR EACH RATION)

Ration	No. of individual values	T.D.N., daily Kgs.			Dig. crude protein daily gms.*		
		Required	Consumed	Per cent of maintenance	Required	Consumed	Per cent of maintenance
Hay	4	3.05	3.17	106	316	301	97
Hay + linseed oil meal 3 : 1	6	2.97	2.28	76	308	468	150
Hay + linseed oil meal 3 : 2	6	2.96	3.11	104	307	812	261
Hay + linseed oil meal 3 : 3	6	3.00	3.95	132	311	1148	369
Hay + linseed oil meal 3 : 4	6	2.99	4.76	159	310	1494	480
Hay + linseed oil meal 3 : 5†	6	3.02	5.60	187	313	1864	599

* Dig. N × 6.25.
† Approximately 5 according to capacity of animals.

The levels of feeding have been translated into terms of maintenance requirements using Brody's tables (1) and expressed as planes of nutrition. In Table 5 are given the total digestible nutrients and the digestible crude protein consumed daily from the different rations compared with the maintenance requirements. In the case of the total digestible nutrients the plane of nutrition varied from 0.8 to 1.9 times maintenance and in the case of the digestible crude protein the plane varied from 1.5 to 6 times maintenance.

SUMMARY AND CONCLUSIONS

1. Using six grade Shorthorn steers, digestibility trials were carried out on six rations, one of hay, predominately timothy, and five of the same hay with increasing quantities of linseed oil meal.

2. The hay was fed at levels of 6.5 kilograms when given as the sole ration and 3 kilograms when given in the mixtures with the linseed oil meal. The latter varied from 1.0 to approximately 5.0 kilograms.

3. Coefficients of digestibility of the linseed oil meal were calculated from the five mixed rations.

4. As the level of feeding was increased, neither the protein nor the ether extract showed any significant change in digestibility while the carbohydrate fraction showed a progressive decrease.

5. This decrease was statistically significant in the case of the total carbohydrates, dry matter and organic matter.

6. The loss in total digestible nutrients over the entire range of feeding was between 2 and 3 per cent. This range in terms of plane of nutrition varied from 0.8 to 1.9 times TDN requirements for maintenance.

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APPENDIX

TABLE 6.—SCHEDULE OF EXPERIMENT

(Ration numbers shown by Roman numerals, animal numbers and period numbers by Arabic numerals)

Period No.	Commencing date	Rations arranged by following animal numbers					
		11	12	13	14	15	16
1	Nov. 9, 1946	VI	V	I	II	III	IV
2	Dec. 3, 1946	II	III	V	IV	I	VI
3	Jan. 4, 1947	III	VI	IV	I	V	II
4	Jan. 28, 1947	IV	I	II	V	VI	III
5	Mar. 1, 1947	V	IV	VI	III	II	I
6	Mar. 26, 1947	I	II	III	VI	IV	V

TABLE 7.—CONSTITUTION OF RATION

Ration No.	Weights, daily, kilograms		Ration No.	Weights, daily, kilograms	
	Hay	Oil cake		Hay	Oil cake
I	6.5 - 7.0	0.0	IV	3.0	3.0
II	3.0	1.0	V	3.0	4.0
III	3.0	2.0	VI	3.0	5.0*

* Approximately, varied slightly according to capacity of individual animal.

TABLE 8.—COEFFICIENTS OF DIGESTIBILITY OF HAY AND OF MIXED RATIONS OF HAY AND OIL CAKE MEAL (COEFFICIENTS IN PER CENT)

Ration	Period	Animal	Coefficients of digestibility						T.D.N. in per cent dry matter
			Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N.F.E.	
Hay 6.5 Kg. to 7.0 Kg.	1	13	57.2	58.3	52.7	22.1	50.1	66.1	55.1
	2	15	56.8	57.6	56.1	42.6	53.7	61.1	54.8
	4	12	55.5	56.3	53.2	35.6	51.7	60.8	52.6
	5	16	57.4	58.8	56.4	43.3	57.0	60.4	55.1
Hay 3 Kg. Oil cake 1 Kg.	1	14	62.8	64.7	76.3	76.5	50.7	69.5	65.3
	2	11	64.2	65.8	76.7	80.4	57.0	67.3	66.4
	3	16	63.7	65.3	77.2	77.1	54.7	68.9	66.1
	4	13	61.3	62.9	73.5	79.4	49.2	67.6	63.0
	5	15	62.0	64.0	66.0	76.5	56.3	65.4	62.8
	6	12	62.9	63.5	74.6	77.3	52.1	67.1	63.7
Hay 3 Kg. Oil cake 2 Kg.	1	15	64.6	66.5	78.8	85.4	46.7	71.3	69.3
	2	12	66.7	68.0	80.5	89.4	54.3	69.5	71.0
	3	11	65.5	67.6	78.3	85.8	50.2	72.4	70.5
	4	16	65.6	67.7	80.5	86.8	54.9	69.0	70.8
	5	14	65.1	67.1	79.4	85.0	52.7	69.6	69.7
	6	13	63.9	65.5	49.5	83.8	46.6	69.8	68.0
Hay 3 Kg. Oil cake 3 Kg.	1	16	68.3	70.0	82.1	88.6	46.9	74.5	74.1
	2	14	67.8	69.8	81.8	87.5	52.5	72.3	74.0
	3	13	66.2	68.1	80.8	85.5	46.1	73.1	72.1
	4	11	67.8	69.6	79.7	89.1	50.9	72.2	73.1
	5	12	67.6	69.0	82.3	89.7	52.2	70.4	73.3
	6	15	67.6	69.5	81.5	87.1	50.7	72.9	73.4
Hay 3 Kg. Oil cake 4 Kg.	1	12	69.3	70.8	83.6	91.4	49.3	74.9	77.2
	2	13	66.0	67.8	82.2	90.5	44.5	69.6	73.1
	3	15	67.4	69.5	80.9	90.2	44.8	74.7	74.7
	4	14	68.8	70.6	84.6	91.0	50.2	72.6	76.4
	5	11	68.8	70.6	83.1	89.9	49.9	73.2	75.8
	6	16	69.2	70.9	83.5	90.3	50.6	72.4	75.8
Hay 3 Kg Oil cake 5 Kg.*	1	11	69.1	71.0	81.6	92.0	39.7	75.3	77.0
	2	16	68.6	70.4	84.9	92.5	44.9	73.9	76.6
	3	12	70.2	71.8	84.2	92.2	42.1	76.6	77.7
	4	15	68.4	70.6	82.2	90.3	48.0	73.0	76.3
	5	13	67.5	69.4	84.6	88.9	46.9	70.9	78.8
	6	14	70.5	72.2	84.3	91.3	47.8	75.4	77.8

* Approximately, according to capacity of animal.

TABLE 9.—COEFFICIENTS OF DIGESTIBILITY OF DRY MATTER AND NITROGEN OF TOTAL RATIONS ARRANGED BY RATIONS, PERIODS AND ANIMALS. (COEFFICIENTS IN PER CENT, ANIMAL NUMBERS IN BRACKETS)

Nutrient	Period No.	Coefficients of digestibility of rations						Means
		Hay	Hay 3 LOM 1	Hay 3 LOM 2	Hay 3 LOM 3	Hay 3 LOM 4	Hay 3 LOM 5*	
Dry matter	1	57.2 (13)	62.8 (14)	64.6 (15)	68.3 (16)	69.3 (12)	69.1 (11)	65.2
	2	56.8 (15)	64.2 (11)	66.7 (12)	67.8 (14)	66.0 (13)	68.6 (16)	65.0
	3	— (14)	63.7 (16)	65.5 (11)	66.2 (13)	67.4 (15)	70.2 (12)	66.6†
	4	55.5 (12)	61.3 (13)	65.6 (16)	67.8 (11)	68.8 (14)	68.4 (15)	64.6
	5	57.4 (16)	62.0 (15)	65.1 (14)	67.6 (12)	68.8 (11)	67.5 (13)	64.7
	6	— (11)	62.9 (12)	63.9 (13)	67.6 (15)	69.2 (16)	70.5 (14)	66.8†
	Means	56.7†	62.8	65.2	67.6	68.2	69.0	
Nitrogen	1	52.7	76.3	78.8	82.1	83.6	81.6	75.8
	2	56.1	76.7	80.5	81.8	82.2	84 9	77.0
	3	—	77.2	78.3	80.8	80.9	84.2	80.3†
	4	52.2	73.5	80.5	79.7	84.6	82.2	75.4
	5	56.4	66.0	79.4	82.3	83.1	84.6	75.3
	6	—	74.6	79.5	81.5	83.5	84.3	80.7†
	Means	54.4†	74.0	79 5	81.4	83.0	83.6	

Means for animals

	An. 11	An. 12	An. 13	An. 14	An. 15	An. 16
Dry matter	67.1†	65.4	63.7	67.0†	64.5	65.5
Nitrogen	79.9†	76.2	75.6	81.3†	74.2	77.4

* Approximately 5 Kgs. according to capacity of animal.
† Not including estimates of missing values.

TABLE 10.—ANALYSIS OF VARIANCE OF PERIODS IN TABLE 9*

Nutrient	Variance due to	D/F	Sums of squares†	Variance†	F
Dry matter	Ration + period	10	499.51		
	Period	5	1.88	0.38	‡
	Error	23	27.89	1.21	
Nitrogen	Ration + period	10	2744.53		
	Period	5	11.68	2.34	‡
	Error	23	116.72	5.07	

* Using method of Yates (5) for missing values.
† Calculated to four decimal places, reported in table to two places.
‡ Variance less than error variance.

TABLE 11.—ANALYSIS OF VARIANCE OF ANIMALS IN TABLE 9*

Nutrient	Variance due to	D/F	Sums of squares†	Variance†	F	Nec. F. at P = 0.05
Dry matter	Ration + animal	10	513.48			2.64
	Animal	5	15.86	3.17	5.24	
	Error	23	13.91	0.61		
Nitrogen	Ration + animal	10	2767.42			2.64
	Animal	5	34.57	6.91	1.69	
	Error	23	93.83	4.08		

* Using method of Yates (5) for missing values.
† Calculated to four decimal places, reported in table to two places.

TABLE 12.—COEFFICIENTS OF DIGESTIBILITY OF LINSEED OIL MEAL CALCULATED FROM MIXED RATIONS WITH HAY

Ration (Kg. oil meal)	Animal No.	Coefficients of digestibility of linseed oil meal in per cent: Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	Total carbo-hydrates	T.D.N. in per cent of dry matter
1	11	85.1	88.1	90.6	101.3	98.0	83.5	86.5	99.5
	12	80.2	79.6	86.3	91.3	40.9	82.5	74.5	90.4
	13	74.4	77.3	85.1	99.8	3.9	83.9	68.8	88.7
	14	80.0	83.9	91.0	91.3	19.9	91.1	79.9	94.5
	15	76.9	81.2	73.5	97.0	89.7	75.1	78.2	87.9
	16	83.5	86.7	91.0	94.3	76.4	88.7	86.8	98.3
2	11	78.1	81.6	85.5	96.2	30.5	87.2	78.2	91.9
	12	80.9	82.2	88.7	102.0	60.4	81.1	76.9	94.0
	13	74.0	76.2	86.8	91.9	9.1	81.8	67.8	87.3
	14	76.8	79.9	87.4	97.4	50.4	80.5	74.2	91.8
	15	75.7	78.6	86.9	94.5	6.5	84.6	72.5	89.4
	16	78.1	81.6	88.5	98.8	65.0	79.2	76.5	93.8
3	11	78.3	80.7	85.0	97.4	42.6	82.2	74.7	91.1
	12	77.8	79.3	88.2	98.8	48.9	78.5	72.3	91.4
	13	75.2	77.9	86.1	92.4	14.4	83.6	72.7	88.6
	14	78.3	81.0	87.6	95.6	50.5	82.9	76.3	92.1
	15	77.8	80.5	86.7	92.9	41.3	84.1	75.8	91.4
	16	79.1	81.4	88.2	95.0	20.6	86.4	76.1	92.0
4	11	77.2	79.5	87.7	96.8	41.5	81.2	72.9	91.2
	12	78.1	79.9	88.4	96.5	37.4	84.2	76.9	92.7
	13	72.5	74.7	86.6	96.8	22.1	75.6	64.7	86.0
	14	77.3	79.5	89.2	97.4	42.0	80.5	73.2	92.2
	15	75.1	77.8	85.0	95.9	16.9	83.8	73.2	88.9
	16	78.0	80.0	87.7	94.9	43.5	80.3	73.2	90.9
5*	11	75.1	77.4	84.7	95.6	9.8	82.1	70.8	87.9
	12	77.6	79.4	87.7	96.8	13.6	84.6	73.5	90.3
	13	73.5	75.9	88.0	94.3	33.8	76.1	67.2	92.7
	14	78.6	80.6	87.9	95.2	34.9	83.9	74.5	91.7
	15	75.3	78.1	85.8	95.6	35.9	79.8	71.5	89.5
	16	76.0	78.3	89.1	98.4	24.6	82.2	70.4	90.3

* Approximately 5 Kgs. according to capacity of animal.

TABLE 13.—ANALYSIS OF VARIANCE OF DATA IN TABLE 12

Nutrient	Variance due to	D/F	Sums of* squares	Variance*	F	Nec. F. at P = 0 05
Dry matter	Ration	4	59 60	14 90	5 63	2 87
	Animal	5	103 89	20 78	7 85	2 71
	Error	20	52 92	2 64		
Organic matter	Ration	4	77 11	19.28	6 35	2 87
	Animal	5	95 93	19 19	6 32	2 71
	Error	20	60 71	3 04		
Nitrogen	Ration	4	5 26	1 32	†	
	Animal	5	94 93	18 99	2 20	2 71
	Error	20	172 21	8 61		
Ether extract	Ration	4	7 28	1 82	†	
	Animal	5	26 63	5 33	†	
	Error	20	169 94	8 50		
Crude fibre	Ration	4	2756 21	**		
	Animal	5	2838 00	**		
	Error	20	10438 34	**		
N-free extract	Ration	4	38 14	9 54	†	
	Animal	5	46 31	9 26	†	
	Error	20	281 85	14 09		
Total carbohydrates	Ration	4	217 30	54 32	5 48	2 87
	Animal	5	246 84	49 37	5 98	2 71
	Error	20	198 30	9 91		
T D N in drv matter	Ration	4	32 96	8 24	1 27	2.87
	Animal	5	80 98	16 20	2 50	2 71
	Error	20	129 61	6 48		

* Calculated to four decimal places reported in table to two places
† Variance less than error variance
** Variance too large

THE PHYSIOGRAPHY OF THE AGRICULTURAL AREAS OF BRITISH COLUMBIA

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Keen interest has been shown recently in the extent of the agricultural lands in British Columbia. Comprehensive appraisals of the nature and extent of these lands have not been attempted for some time. Perhaps the diversity prevailing in the surface features of the province, over even short geographical distances, has discouraged attempts at description. However, a broad physiographic picture appears to offer a logical background upon which a sound appraisal of agricultural lands in British Columbia may be based. While it may not yield such pertinent information as acreage and soil type, it will indicate the location of important areas and their probable size.

THE REGIONAL PHYSIOGRAPHY AND ITS DIVISIONS

The political province of British Columbia falls almost entirely within the North American Cordillera. Only north-eastern British Columbia falls within the Great Plains or the Tramontane region. In British Columbia, as indeed over most of its length, the Cordillera may be divided into three longitudinal belts, western and eastern, both with a highly uneven topography with high summits and deep valleys, and a central belt with lower summit elevations and a semi-plateau topography. The transitions between the belts are broad and definite boundaries are often hard to discern.

Within the three belts the physiographic provinces are often quite well defined by reason of deep rather continuous structural valleys which parallel the belts or cut across them at usually acute angles. These provinces are well designated by Kerr (39) and Schofield (61) and others (19) and are portrayed in Figure 1. In our modification the trenches are given the same status as the mountain ranges.

The Western (or Pacific) Belt is partitioned by a major downfold, the Coastal Trench, which extends clearly defined from southern Washington into the Alaskan Panhandle. The trench is probably structural in origin (46), rather than erosional (50), and structural relationships with the Willamette Valley of Oregon and the San Joaquin and Sacramento Valleys of California might be claimed. West of the trench in British Columbia lie the Insular mountains, that is, the mountains of Queen Charlotte and Vancouver Islands. East of the trench lies the Coast Range which, for all practical considerations, extends from the southern to the northern boundaries of the province. A few (61) recognize the Cascade Range, which lies south of the canyon and delta of the Fraser River and extends far southward into the Pacific Coast States, as being separate.

The Central Belt, often referred to as the Interior Belt of Plateaux, in following the general N.W.-S.E. trend of the Cordillera, is limited in extent along the southern border of the province but occupies a great area in the

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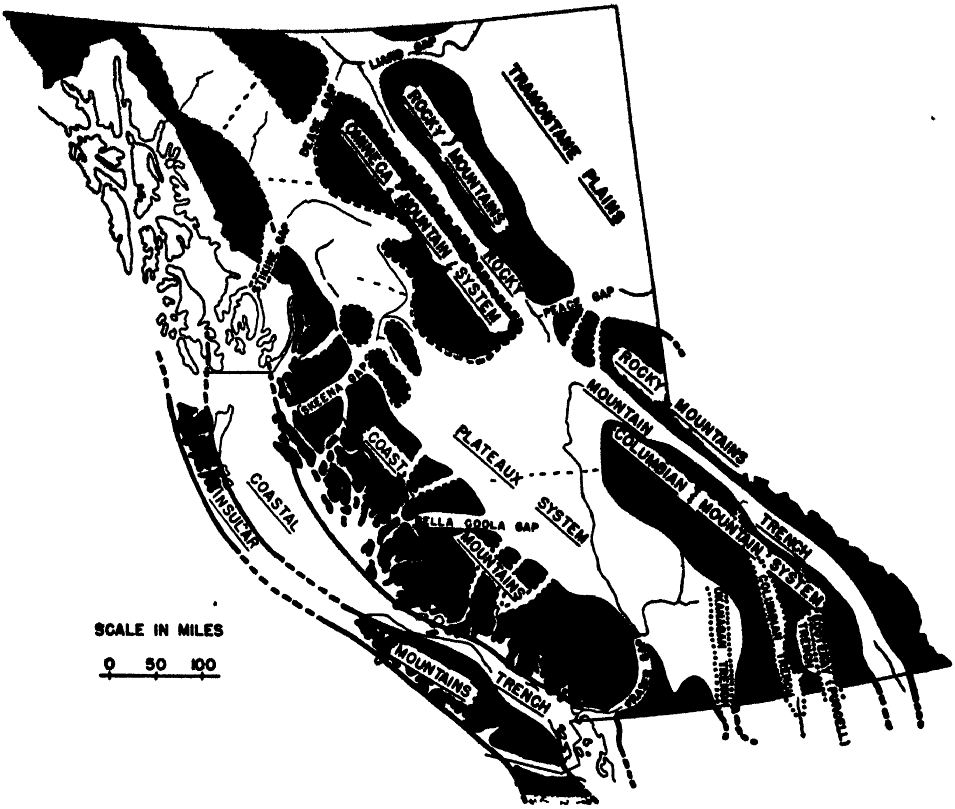

FIGURE 1. Physiographic Divisions of British Columbia.

central portion and appears to be maintained fairly definitely to the northern border. The physiographic provinces within this belt are not easily defined although a definite basis for division may exist (46) for the southern part. The Fraser Plateaux (southern section) and the Nechako Plateaux (central) are divisions currently recognized.

The Rocky Mountain Trench, a principal structural valley which follows the general longitudinal trend of the mountain chains, separates the two principal mountain masses in the eastern belt. The trench, one of the major physiographic features of the continent, has great length; it is detectable as far south as Flathead Lake in Montana, extends northwestward through British Columbia, and fades out in the Yukon territory near the Arctic Circle. The Columbian Mountains to the west of the trench consist of several parallel ranges and trenches and extend from Idaho and Montana to Central British Columbia to a point where the Rocky Mountain trench and Interior Plateaux seem to connect. However, northward the counterpart of these mountains is again in evidence in a system tentatively designated as the Omineca Mountains. The Rocky Mountains to the east of the trench are a long, uniform mountain chain and include a few structural valleys. No subdivisions of importance are recognized within these mountains from the 49th parallel to the Liard River near the northern border of the province. Only once, in the vicinity of Peace River Pass, is the series of high mountain summits broken appreciably.

The Tramontane area of north-eastern British Columbia is essentially part of the Great Plains physiographic province (1). In conforming with the underlying rocks, the surface is essentially one of low relief. Some highland plateaux, possibly northern counterparts of the Cypress and Sand Hills of Alberta are seen above the general plains surface in the far northeast.

For the purpose of giving a simplified picture the following few physiographic divisions have been recognized. The Belts and their divisions deserve the status, respectively, of physiographic regions and provinces.

The Western Mountainous Belt
- *(a)* The Insular Mountains.
- *(b)* The Coastal Trench.
- *(c)* The Coastal Mountains.

The Central Belt of Interior Plateaux
- *(a)* The Fraser Plateaux.
- *(b)* The Nechako Plateaux.

The Eastern Mountainous Belt
- *(a)* The Columbian (and Ominecan) Mountains.
- *(b)* The Rocky Mountain Trench.
- *(c)* The Rocky Mountains.

The Tramontane Plains

THE INSULAR MOUNTAINS

Bordered by the Pacific Ocean the westernmost physiographic division of the province is constituted in the mountains of Queen Charlotte and Vancouver Islands. The chain of mountains is not uniformly developed. To the south the mountains of Vancouver Island are separated from the Olympic Mountains of Washington State (to which they bear relationship) by the deep ocean-filled channel, Juan de Fuca Strait. The summit elevations of Vancouver Island seldom exceed 3000 ft. but in the north a few exceed 7000 ft. The chain is broken again by the salt water filled trough, in part known as Queen Charlotte Sound, between Vancouver Island and the Queen Charlottes. Three summits in the latter group just exceed 3000 ft.

The rocks forming the core of the Insular mountains are altered sedimentaries and volcanics largely of Carboniferous and Jurassic ages and, if contrast is made with the Coast Range to the east, have conferred upon the Insular mountains a relatively subdued form. The Insular range, however, has many erosional features in common with the Coast Range and Interior Plateaux. By late Tertiary times, over the southern and central parts of the province, erosion had reduced the land surface to a fairly high degree of uniformity especially in the southern part. The old upland surface is now represented in a striking concordance of summit and ridge elevations. The present "upland surface" in the south is about 1200 ft., in the north 3500 ft. Uplift and erosion occurred at the close of the Tertiary and prior to the Pleistocene a new coastal plain had developed on the flanks of the Insular mountains (13, 14, 15, 16).

During the Pleistocene period the Insular province was covered, except for a few high summits, at least twice, by ice (13, 25). Tertiary valleys, both subsequent and transverse, were severely modified by ice action. Fiord development is marked on the western slopes and less marked on the eastern slopes. Post glacial influences in the mountains are not striking; a recent uplift of some 150 ft. – 500 ft. is evident in the stream gradients (64). Drainage, not simple, is principally to the east and west from the Range axis.

Insular Mountain Soils

(a) The Alberni Basin

One intermountain basin of some 100 sq. miles area possesses a topography suitable for agriculture. The basin (Figure 2) in which the city of Alberni is located appears to be an old subsequent valley of obscure origins carved out of "soft" Cretaceous and Tertiary sediments. It is connected with the long Alberni fiord on the west, on the east by a low pass to the coastal plain of eastern Vancouver Island and on the north and south with several fiord-like lake filled valleys. At its widest the basin is 15 miles, was probably well defined in Tertiary times, and has been filled with glacial and post glacial deposits. Marine, lacustrine and stream action have resorted the glacial debris and some recent allluvium has been deposited. There is in all some 45,000 acres of land with a topography suitable for arable agriculture, 30,000 acres of which is stony and coarse. About 4000 acres are now cultivated (64, 65). The basin contains some of the finest forest soil in British Columbia.

On southern Vancouver Island some flat swamp covered areas on the old land surface have a limited agricultural value.

(b) The Tofino-Long Beach Platforms

Conveniently considered with the Insular mountain province are the narrow strips of lowland which occur at intervals along the west coast of Vancouver Island. These are remnants of a coastal plain built up against submerged mountain slopes as small embayments in Tertiary times (16). The lowland strips are seldom more than 1 or 2 miles wide and are mainly underlain by soft sedimentary rocks; a few planed granites and crystalline rocks also underlie some sections. The areas were spared intense glacial action. They appear to represent marine platforms submerged in the Pleistocene and recently elevated from the sea in a post glacial uplift of 300 ft. The acreage of arable land is probably small but at present supports a few farms and airfields.

No other areas of agricultural value have been recognized in the mountain belt of Vancouver Island.

The arable lands in the insular province are well leached podsols; the climax vegetation is principally heavy coniferous forest.

THE COASTAL TRENCH

The belt or trench of depressed land separating the two more or less parallel members of the Pacific mountain belt, and extending with a few interruptions from the Gulf of California to Cook Inlet, Alaska, in British Columbia takes the form of a series of submerged longitudinal basins.

FIGURE 2 Alberni Basin on Vancouver Island The macrotopography is uniform, the microtopography, rough Excellent forest soils, some arable resorted till and alluvium

R C A F Photo

FIGURE 3 Lower Fraser Valley (Chilliwack District) showing alluvial delta with the Hope Mountains rising sharply in the background

—Artray Photo

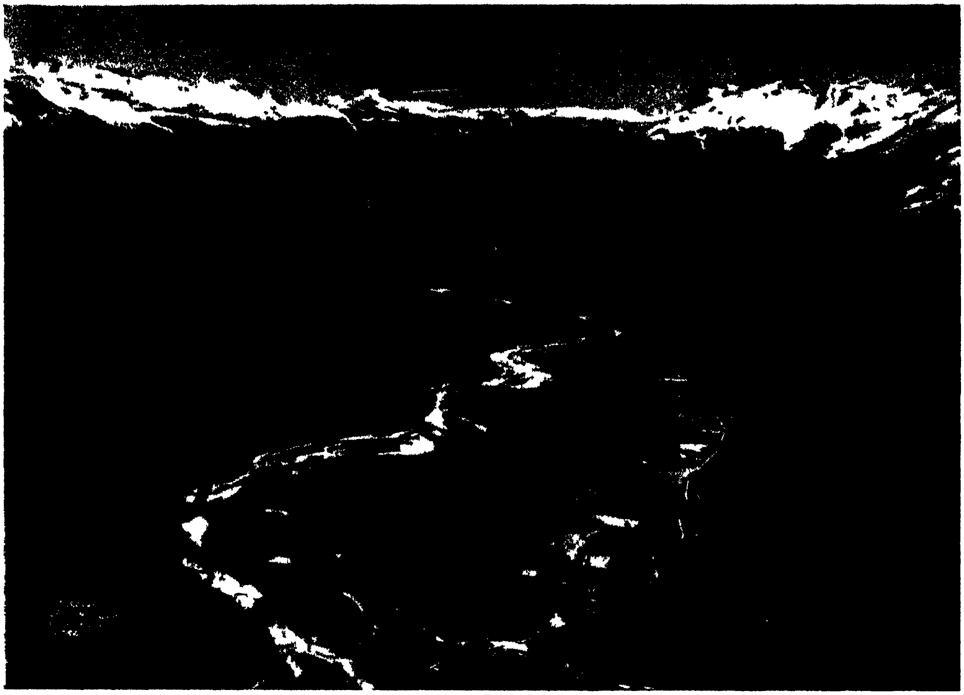

FIGURE 4 Bella Coola Valley in the Coastal Mountains A typical U-shaped valley, silt filled, at the head of a major fiord.

—*R C A F Photo*

FIGURE 5 "White Silts" at Summerland in the Okanagan Trench They present a bold cliff-like appearance near the lakeshore but dip gently above. Orchard development here is almost confined to the "White Silts".

—*R.C.A.F. Photo*

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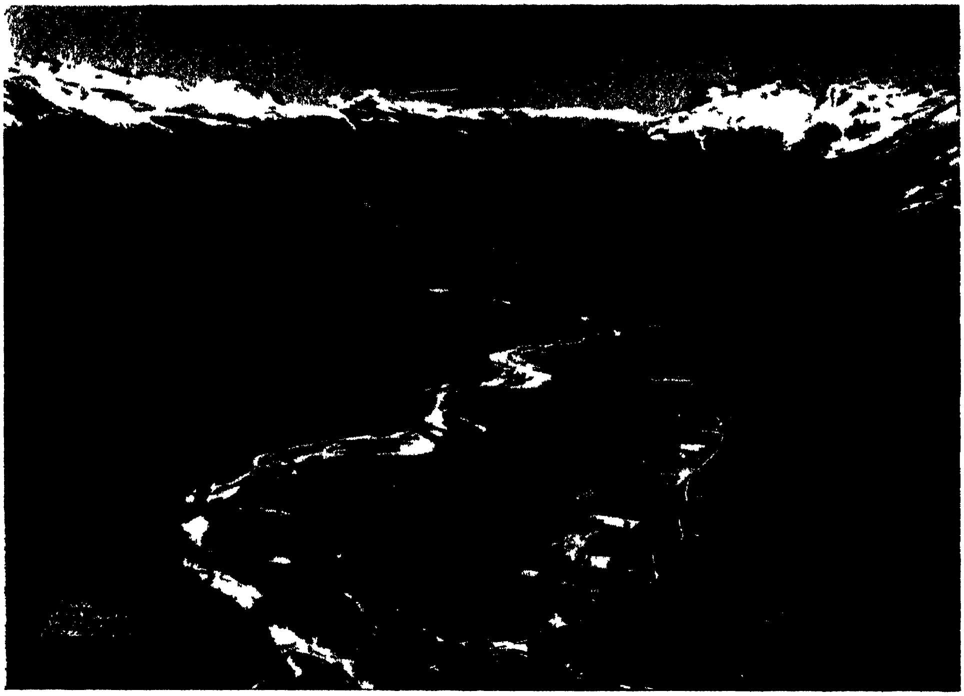

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—R.C.A.F. Photo

Peacock (50) has subdivided this physiographic division in British Columbia into two sections, the Hecate Basin comprising part of Graham Island, Queen Charlotte and Millbank Sounds and the Gulf of Georgia Basin comprising Puget Sound, the Lower Fraser Valley, the coastal plain along the eastern shore of Vancouver Island, and the Gulf of Georgia. The two basins are connected by the relatively narrow passage of Johnstone Strait. In the latitudes of British Columbia much of this division is ocean filled. An emergence of only 600 ft., however, would créate two great valleys occupied by a few lakes and almost completely surrounded by mountains.

The origin of the Coastal Trench is a matter of some dispute. It is variously described as a "downfold," a "trench" and an "intermont valley belt." In Cretaceous times sediments of considerable thickness, limestones and shales, were laid down in the basins. To-day these are exposed along the above water fringes of the trench and are often associated with the topographically uniform areas of agricultural importance. Sedimentation again occurred in Tertiary times and, again around the basin margins, Tertiary sedimentaries are associated with lands topographically suitable for agriculture.

During the Pleistocene, certainly once and probably twice, the Georgia basin was filled with southward moving ice. At the ice front, south of Tacoma in Washington State, a thickness of 1500 ft. was probably attained; farther north the ice was at least 6000 ft. thick. Little is known of the influence of ice in Hecate Basin. Local glaciation may have lightly eroded the lowland on Graham Island in the Queen Charlottes (44).

The southward movement of the Gulf of Georgia glacier unmistakably modified the surface features along the now exposed basin margins. High wave cut cliffs conspicuously mark outwash deposits around Puget Sound and the Gulf. Glaciers too from the fiord land to the east deposited great quantities of debris. Two till sheets, both of Wisconsin time and one interglacial deposition are recognized (9, 25, 33).

A post glacial uplift of several hundred feet is deduced from the presence of raised beaches, wave cut terraces and cliffs along the margins of the basins. In the lower Fraser Valley the uplift has exceeded 600 ft. (31); on eastern Vancouver Island and the Queen Charlottes it was much less.

The Arable Areas of the Coastal Trench

While much of the coastal trench in British Columbia is submerged the non-submerged areas comprise one of the largest agricultural parts of the political province.

(a) The East Coast Plain of Vancouver Island

Associated with the Gulf of Georgia Basin are the principal agricultural soils of Vancouver Island (Figure 10). The coastal plain, on eastern and southern Vancouver Island, underlain by "soft" basin rocks or planed crystalline rocks has provided a suitable surface for accumulation and deposition of a soil mantle. The plain varies in width from 1 to 15 miles and breaks sharply with the insular mountains. Its elevation ranges from

100 ft. to 500 ft. While there are several valleys paralleling the plain and while the Gulf Islands and their troughs are predominantly north to south in trend, all of the many streams from the Insular mountains and coastal swamps flow eastward across the plain sometimes dissecting it quite deeply. Weak marine terraces and beaches are found across the plain up to the 350 ft. contour. Wave cut cliffs characterize much of the present coast. Deltas both raised and recent are found at the mouths of most of the streams. In the Victoria area a number of small basins, filled with marine tills, silts and sands, have risen from the Pleistocene Sea to provide some of the best farmland on the Island. While the macrotopography of the Coastal Plain appears favourable for the development of large areas of arable land the microtopography belies the impression. The microsurface of the coastal plain of Vancouver Island is, except for the scattered recent deltas and lacustrine deposits, rough. Excessively drained terraces, knolls and moraines, and poorly drained flats make for a heterogeneous soil pattern over all sections. Of 625,000 acres of coastal plain surveyed, Spilsbury (65) found only 200,000 arable with 90,000 already occupied. Perhaps an additional 200,000 acres of basin lands remain to be soil surveyed in the Gulf Islands and Northeastern coast of Vancouver Island; most of this, however, is poorly drained or has a thin soil mantle. Some of the superior forest soils of the continent are on the Island plain.

(b) The East Coast Plain of Graham Island

Graham Island the largest of the Queen Charlotte group is the only island having some surface suitable for arable agriculture. Abutting the Insular mountains on the northeastern corner of the island is one of the largest smooth land surfaces in British Columbia (1, 44). It occupies about one-third of the island, some 1800 sq. mi. The area is underlain by partially or wholly unconsolidated sediments of Tertiary age with some areas of younger Tertiary volcanics. The surface is low and undulating with few points over 200 ft. elevation. Shallow lakes occur frequently and streams crossing the plain meander conspicuously. Much of the Graham Island plain may have been submerged in recent times; evidence for this lies chiefly in the wave cut cliffs of the eastern shore. Glacial action appears to have been limited to the Insular mountains and even here it was probably slight.

While much of the soil of the lowland area is fine and has a satisfactory topography it is seldom classed with the agricultural resources because of the cover of muskeg and dense forest.

(c) The Lower Fraser Valley

Another agricultural area properly associated with the Coastal Trench is a transverse valley or embayment on the eastern side of the Gulf of Georgia, the Lower Fraser Valley (Figure 11). It enjoys a continuous connection with the Puget Sound plain in Washington State to the south and a broken relationship with limited areas of Cretaceous and Tertiary basin rocks to the north. The fan-shaped lowland is about 80 miles from the Gulf waters to the Valley head and about 40 miles across the front. The lowland floor breaks sharply with Coast Range Mountains of 4000—8000 ft. in elevation to the north and high Cascade Mountains to the

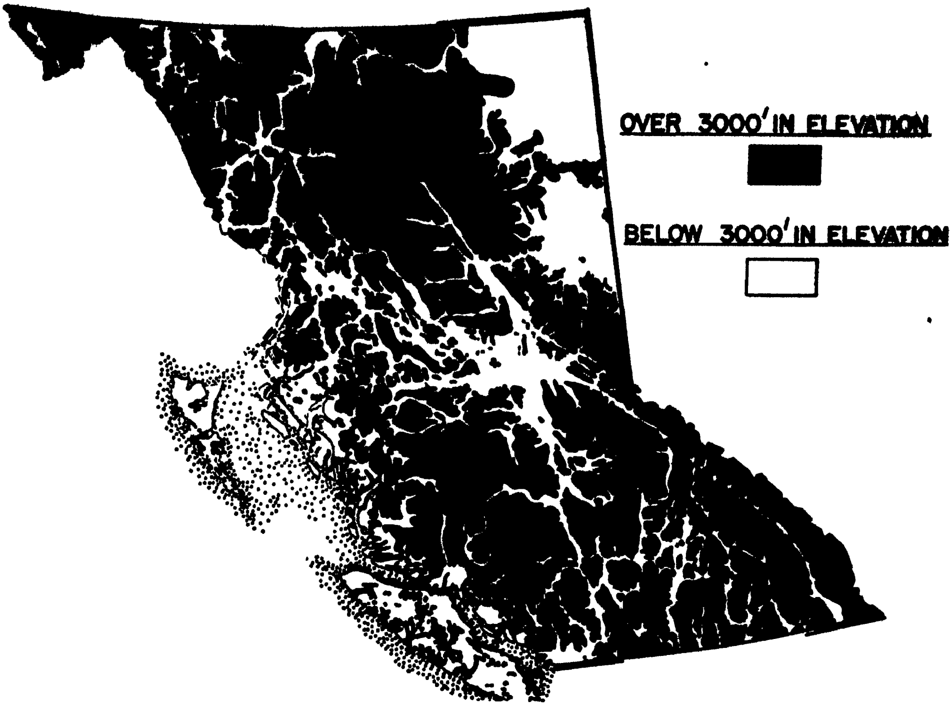

FIGURE 6. General agriculture, apart from range livestock production, cannot be successfully carried on at elevations of over 3000 feet in most of British Columbia. Less than 25 per cent of the total area of the province lies below the 3000 feet contour.

south. Altered Cretaceous sediments and consolidated Tertiary sandstones, shales and conglomerates outcrop occasionally sometimes up to the 800 ft. contour along the mountains. Downwarping and erosion of these basin rocks has occurred but glacial detritus and recent alluvium have filled in to give the whole a fairly uniform surface. At the eastern end of the lowland the fill has built up around steep-sided "nunataks" such as Vedder and Sumas mountains.

During the Pleistocene the lowland was covered with ice to a probable depth of 5000 ft. Ice, from the Gulf of Georgia glacier, from the great fiords to the north, such as the Pitt and Harrison valleys now lake-filled, and from the Hope Mountains (Cascades) must all have contributed to the Pleistocene history of the Lower Fraser Valley. Some interglacial deposits and two till sheets are recognized in the area (38). Retreat of the ice and the accompanying post glacial uplift of 600 or 700 ft. is evidenced over the lowland surface in old marine beaches and weak terraces, in abandoned channels of post glacial streams, in kettles and moraines (48).

Across the lowland area (Figure 3) flows the silt laden Fraser river. Below Yale, where the river emerges from its Coast Range Canyon, the stream takes a direct course to the sea. Ten miles from its debouchement at the Gulf its water splits into several channels. Over much of its length across the lowland the river is tidal. At Yale, Hope and possibly at Chilliwack the river is cutting into its raised deltas. Across a wide front and over a large area in the Gulf of Georgia the river is depositing. The

delta front appears to be advancing 12 ft. a year (30, 32). The filling of the lowland with till and alluvium has "dammed" the fiord valleys of several large streams flowing from the Coast Mountains on the north. As a consequence a number of these valleys are now, or were recently, lake-filled. Some of the lakes such as Pitt Lake and Harrison Lake are 35 miles in length.

Some 500,000 acres of land in the Lower Fraser Valley is topographically suitable for agriculture and by virtue of its proximity to large centres of population almost all must be classed as agricultural. Recent "delta" or lowland soils principally clays, loams and peats, obtain over 45 per cent of the area; upland soils, mainly glacial till, moraine and loess, varying in texture from loam to sand, comprise another 25 per cent of the arable land; about 30 per cent of the area is in upland soil with adverse topography or excessive subdrainage (35). Most of the lowland has been dyked and ploughed. Considerable areas of upland remain in second growth forest.

The upland soils of the coastal trench are podsolic and except on southern Vancouver Island show incipient lateritic development. The colors in the surface horizons of the zonal soils range from reddish to yellowish brown. Much of the most productive farmland is associated with recent alluvium; here profile development is weak. Ortstein, Glei and bog soils are commonly found over the lowlands of the Coastal Trench.

THE COASTAL MOUNTAINS

From the Lower Fraser Valley northwestward into Alaska the great physiographic element, the Coastal Mountains extends in an almost unbroken chain. The range is built of great masses of plutonic rock, mainly grano-diorite, which "invaded" a heavy cover of sedimentary and volcanic rocks in Jurassic and Cretaceous times. Cover or roof rocks now exist only in isolated patches, mainly on the north-eastern side of the range. From sea level the range appears rugged but as in the insular mountains the peaks and close set ridges show a striking concordance in elevation. The range thus appears as a vast dissected plateau 100 miles wide and 1000 miles long with a vague gently arched longitudinal axis of 9000 ft. in south, rising to 11,000 ft. at latitude 52°. Farther north the axis drops, again to rise before the range is "lost" in Alaska. Peaks rise above the general axis level by as much as 3000 ft. The highest peak in the range, wholly in British Columbia, Mount Waddington, rises to 13,260 ft.

The principal drainages of this physiographic province are transverse to the trend. The largest rivers flow from the Interior Plateau through the range by way of deep valleys forming veritable corridors or gaps. Most of these streams such as the Fraser, the Homathko, the Kleena Kleene, the Dean, the Skeena, the Nass, the Stikine and the Taku are actually deepening their courses. The seaward margin of the range is riven by a maze of steep-sided tidewater inlets leading far into the range, a typical fiord land. Most of these have high steep parallel walls, are narrow and straight or cranked by abrupt deflections at high angles. A dominant structural pattern of valley elements arranged longitudinally and trans-

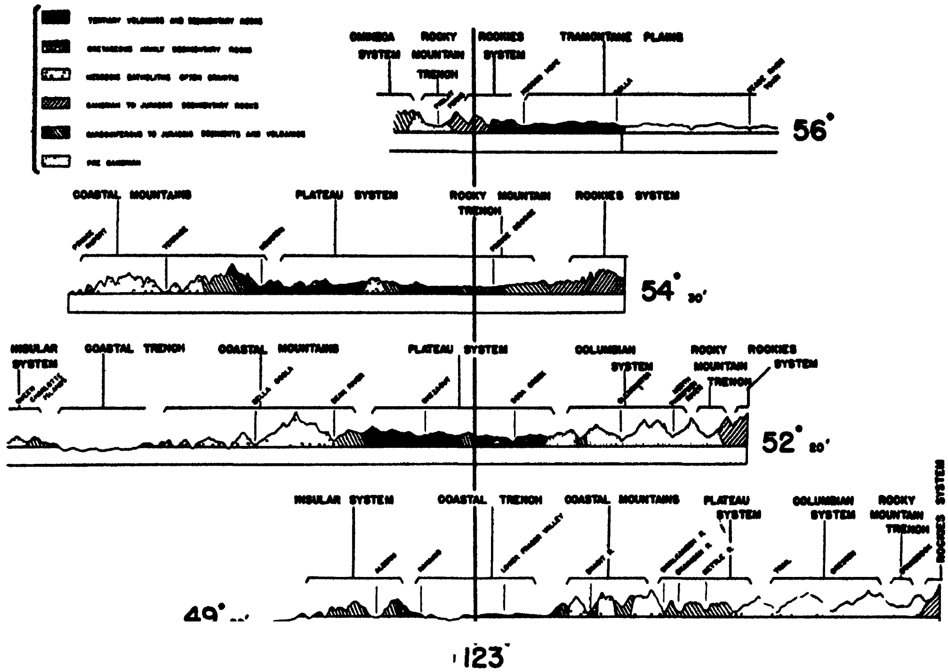

FIGURE 7 Cross sections of British Columbia at four latitudes showing approximate topography and nature of the country rock

versely to the trend of the range can be distinguished accounting for much of the cranked nature of the fiords and interconnecting through valleys (50).

During the Pleistocene, ice moved southwestwardly from the Central Belt across the Coast Mountains chiefly by way of through valleys. While the higher peaks were not overridden, most of the range was severely modified by the ice and massive sheets of drift mantle the lower slopes of the ranges and margins of the coastal trench. In post glacial and glacial times sporadic volcanism has occurred.

Agricultural Lands Within the Coast Range

(a) The Mainland Fiord Heads

Only a few small areas, having agricultural value, exist in this physiographic province. Many streams, often glacier fed, eroding through bedrock and till have built up and are building up rapidly high grade deltas at the heads of the fiords. Only two deltas have seen any noteworthy agricultural development, the Squamish Valley at the head of Howe Sound and the Bella Coola valley (Figure 4) at the head of North Bentinck Arm. These areas embrace only a few thousand arable acres and support a small agricultural population. Much of the better land, the raised deltas and resorted drift, is subject to flooding by swift flowing streams.

(b) The Terrace Valleys

Two intermountain valley areas, Pemberton Meadows and the Terrace Valley are noteworthy. The Terrace area (40, 41, 42), close to sea level, on the Skeena River, enjoying a coastal climate, is located at the junction

of several drift filled valleys. It has close connections with salt water by way of the Skeena River and Kitimat Arm fiord. Much of the valley deposit is coarse drift; some is terraced semi-lacustrine and flood plain gravel, sand and loam. Much of the finer deposit undoubtedly originates in the recent unconsolidated volcanics of the area and in powder from glacier fed streams. The total acreage of topographically uniform land at Terrace is 66,000 acres and possibly 50 per cent is fine textured enough to be arable. These coarse valley soils, however, support an excellent forest growth.

(c) The Pemberton Valley

The Pemberton Meadows area consists of recent alluvium and raised delta deposited, at the head of Lillooet Lake, by glacier fed streams. The valley is long, steep sided and U-shaped on cross-section and at one point is over 7 miles wide. The elevation is comparatively low (1000 ft.). Unconsolidated quaternary volcanics and glacial flour have contributed heavily to the local stream loads. Stream control is important in the use of the arable lands, some 25,000 acres of reclaimable azonal soil.

The Interior Plateaux

The boundaries of the physiographic province in the central belt, usually known as the Interior Plateau, are difficult to place. The area is about 500 miles long, 100 to 300 miles wide and trends northwest from the 49th parallel. The eastern boundary, or contact with the Columbia Mountain System, may be roughly limited by the valleys of the Kettle, Adams, Clearwater and Willow Rivers. A branch of the Cascade range, known locally as the Okanagan range, bounds the plateau on the south. To the southwest from Lillooet to the 49th parallel the boundary area is broad and presents characters of both Interior Plateau and Coast Ranges. In the northwest central area, from Lillooet to Hazelton, the boundary is definite with foothills and mountain ranges breaking quite sharply with the plateau surface. The northern boundaries are, for want of information, difficult to define; the plateau surface, however, is probably recognizable in the far northern parts of the province (34).

The Okanagan and Similkameen valleys on the south drain to the Columbia River. By far the greatest river system draining the Plateau is that of the Fraser and its tributaries, the Thompson, the Chilcotin, and the Nechako Rivers.

The plateau province consists essentially of large areas of rolling upland separated from each other by deep valley trenches. In the south the plateau surface lies from 4000 to 6000 feet above sea level (Figure 7); its elevation gradually decreases towards the north where it may reach a minimum elevation of 2200 feet around Prince George. Since the main routes of travel are along main valleys with steep-sided eroded shoulders, the casual observer gains the impression, not of plateau but of mountainous upland. Actually streams crossing the upland generally have low gradients and are frequently dammed by small Pleistocene moraines to form extensive swamps and lakes. The upland surface, while not flat, is not mountainous. The areal ratio of upland to valley in the south is about 3 to 1; in the north, valley often merges imperceptibly with upland.

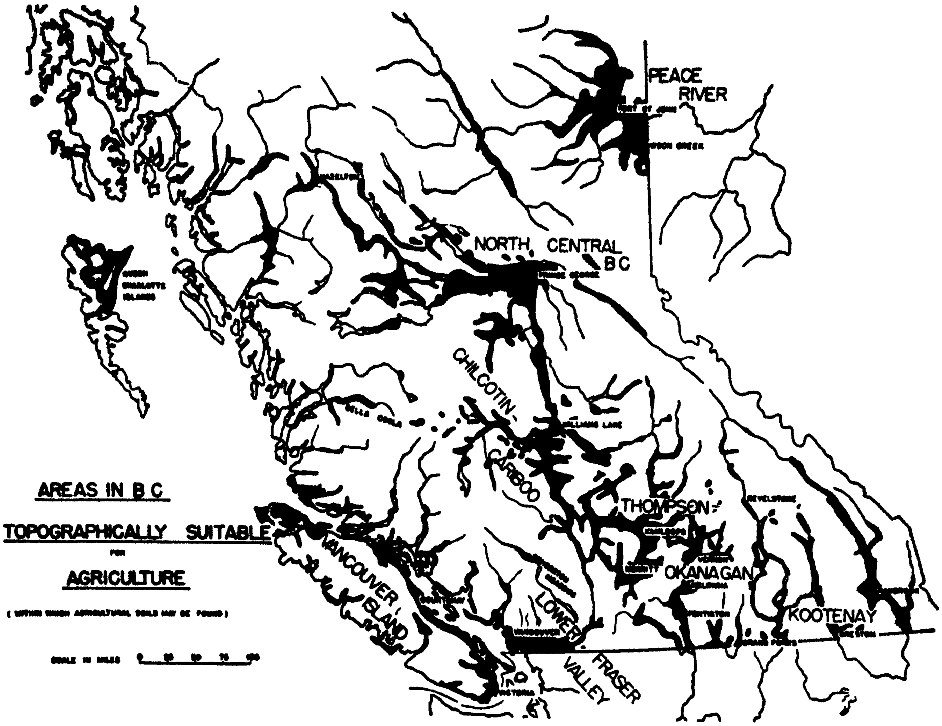

FIGURE 8. Areas in British Columbia within which agricultural soils may be found are in black. The map, adapted in large part from that of Whitford and Craig, shows the general distribution of agricultural lands in the province.

The present upland surface conforms only partially with the underlying rocks. In the strictest sense the term plateau is then not correct. Submergence in Carboniferous times is indicated in a wide distribution of limestones, quartzites and submarine flow rocks over the area. Granitic rocks, frequently occupying large areas in the south, witness the great plutonic intrusion which commenced in Jurassic times and which resulted in the first great elevation of the Coast Range and Columbian systems to the west and east. Cretaceous rocks occur along the western fringes of the plateau and point to a period of unroofing of the Coast Range batholith (27, 58).

During the early Tertiary, in the south at least, the area was probably rough. A number of isolated basins developed in which lacustrine sediments were deposited. A great resurgence of volcanism occurred later in the Tertiary, accompanied by the accumulation of great depths of lava; these depositions, lacustrine and volcanic, relatively undisturbed to-day, account for much of the level topography of the plateau surface. Still later in the Tertiary the plateau area was uplifted and many of the principal valleys were dissected. No part of the plateau remained free of ice during the Pleistocene. Glacial erosion, while not extreme in some places, was extensive in others. Fresh bedrock was exposed and much loose mantle swept into valleys. Ice and water scoured and remoulded many of the main valleys and disorganized existing drainage. As the ice retreated, lacustrine, flood plain and terrace series were laid down over widely scattered

areas and at nearly all elevations (47, 52, 38). Numerous lakes and relict streams which owe their existence to disorganized drainage are still extant. Adjustments, at least partly isostatic, are still taking place.

A number of physiographic subdivisions may be recognized in the Interior Plateau. In the south, Matthews (46) recognized three general N.W.-S.E. axes of elevation alternating with three axes of lesser uplift. In order from east to west the axes correspond to the Kettle Depression, the East Okanagan Highland, the Okanagan Depression, the West Okanagan Highland, the Princeton-Kamloops Depression and the Western Highlands. Only the lowlands have much agricultural interest.

(a) The Kettle Depression

The Kettle Depression is a rather small intermontane trough drained by the Kettle Rivers which flow south. The narrow trough is about 45 miles long. The plateau surface adjacent to the depression is fairly well preserved and arable lands are found upon it, viz., several thousand acres of dry farm land around Bridesville. Scattered post-glacial terraces and recent alluvium along the valley bottom, never more than 5 miles wide, support a limited agriculture. The agricultural area is nowhere more than three miles wide (Midway and Rock Creek) and is usually narrower. Some of the scattered arable land is irrigated and used for hay production, hay being a limiting factor in the use of adjacent range on valley side, upland and alpine surfaces.

(b) The East Okanagan Highland

The East Okanagan Highland, with a maximum summit elevation of 7000 feet, supports a small range sheep and cattle population. Soils are shallow at best and support a poor forest. Swamps and lakes in the area serve as reservoirs of irrigation water for adjacent lowland.

(c) The Okanagan Depression

The Okanagan Depression extends for at least 150 miles from the 49th parallel at Osoyoos to Shuswap Lake and constitutes the largest intermontane trough. The valley bottom in the south is 3 to 6 miles and in the north 12 to 15 miles wide (62). Armstrong, in the north, has an elevation of 1200 feet and Osoyoos, in the south, 800 feet. The valley floor surface shows some local relief, rarely exceeding 800 feet. Characteristically, the valley shoulders rise abruptly to the upland surface at 4000 to 6000 feet elevation and are often sharply dissected by youthful canyons made by subsequent streams flowing almost directly down from the tilted plateau surface. Drainage of the Okanagan Depression is effected by two major longitudinal streams—the Okanagan River (and Lake) flowing southward to the Columbia River and the Shuswap River (and Lake) flowing northward and westward to the Fraser River. An outstanding feature of the depression is the gradient produced by overdeepening through glaciation and some quaternary sedimentation. It is said that two dams, each less than 150 feet high, one at Okanagan Falls in the South Okanagan and one at Wallachin on the Thompson River, would produce a single waterway 275 miles long. Almost 60 per cent of the trough is now occupied by lakes, the direct or indirect results of glacial overdeepening, or damming

by alluvial fans and moraines. Important "East-West" valleys run into the trough in the north which in turn connects several broad valleys running parallel to it. A complex rectangular pattern of valleys thus formed involves several drainages separated by low passes. As bottoms and drainage channels of post-glacial lakes formed as the last Pleistocene ice sheet retreated, these valleys share a common but complex history.

The major agricultural soils of the Okanagan Valley are associated with striking terraces of laminated silt which flank the valley sides and fill its bottom (Figure 12). The terraces (Figure 5) are sharply cliffed at lake-shore but above are separated by moderate slopes. Their thickness varies but is commonly several hundreds of feet. Uppermost prominent terrace above Okanagan Lake is at the 1800 feet elevation which coincides well with the elevation of the outlet channel or spillway for the late Pleistocene Okanagan Lake placed by Flint (24) near Vasseaux Lake. The lacustrine or semi-lacustrine origin of the silts is established beyond doubt. It would seem that residual glacier ice, in persisting in the narrow trough south of Vasseaux Lake dammed the meltwater north of it. In the lake north of the dam terrace masses were built out over the margins of wasting stagnant ice. Wastage of ice at the dam permitted the drainage to return to its former channel along the depression floor. The silt now occurs brokenly along the trough and is widest at the mouths of tributary streams; a maximum width of 4 miles of silt along the Okanagan Lake is attained at Kelowna; farther north it completely fills the depression bottom and is wider. Over much of the length of the depression the terraces or "benches" are narrow and interrupted by rocky outcrops. The terrace surfaces are usually smooth and dip moderately towards the valley axes. For the most part the silt consists of feldspathic rock flour and because of their creamy white colour were termed by G. M. Dawson, "the white silts." Sometimes the terrace deposits are sands and gravels. Around Rutland, for example, an important soil series consists of shallow sandy loam verging on glacial till.

While the white silts constitute the economically most important source of arable land in the Okanagan, soils almost directly derived from a fairly stone-free till obtain over appreciable areas north of Kelowna and in the south around Oliver. Recent fans, built by turbulent streams from the valley shoulders, sometimes of coarse gravel and sometimes of fine reworked terrace silts, occur irregularly along the valley bottom.

The area in the Okanagan depression having a topography suitable for arable agriculture is probably less than 400,000 acres. Only the Lower Fraser Valley rivals the area in agricultural importance. At present something over 50,000 acres, mainly white silts, are under irrigation in the Okanagan Valley. In addition there are considerable acreages of groundwater soils, needing no irrigation, and dry farmed soils. Except for a few groundwater types the arable soils are mainly zonal pedocals. There is a strong altitudinal and latitudinal zonation to be observed in the profiles along the depression (36). At low elevations and in the south, under physiologically dry conditions, brown soils are developed; at higher elevations and latitudes dark brown and black pedocals and a succession of intermontane podsolic soils are recognized. Before settlement much of the land classed as arable was in native bunchgrass; some was in montane forest (28).

(d) The West Okanagan Highland and Similkameen Valley

The West Okanagan Highland parallels the Okanagan Depression for 150 miles. It is 20 to 30 miles wide and summits of 6500 feet are noted in the south and 5000 feet in the north. The upland surface is generally well preserved. In the north, however, a series of "through" valleys related to those of the northern Okanagan depression, occupied by the Shuswap and Salmon Rivers, Chase and Monte Creeks, and Sicamous and Adams Lakes, dissect the highland in nearly rectangular pattern. Most of the agriculturally useful valleys are steep-sided and flat-bottomed at elevations of from 1500 to 2500 feet and are often filled with terrace sediments of fairly fine texture. The agricultural area, adjacent as it is to large areas of sheep and cattle range on the upland surface, is used primarily for hay production. The total arable acreage must exceed 20,000 acres; an appreciable amount is under irrigation. The acreage is scattered, however, but where valleys meet, arable areas 3 miles or more across, as at Westwold, may obtain.

While most of the West Okanagan Highland is too high for arable agriculture it provides summer grazing for range livestock and water storage for irrigation. And in the south the Highland is again dissected deeply by two through valleys, the Trout Creek Valley, with little arable land, and the Similkameen River Valley. The antecedent Similkameen River crosses the highland north of the 49th parallel in a deep narrow trench 35 miles long and 5000 feet deep. From Hedley to Keremeos, except at the junction of the Ashnola River, the bottom seldom exceeds 4000 feet in width but from Keremeos to the American border, in a few places, it exceeds 15,000 feet.

About 30,000 acres of land with a topography suitable for agriculture are found in the bottom; more than 3000 of these acres are under irrigation. Narrow terraces line the valley sides to 300 feet above river level. Most of the arable soils are the brown pedocals of the terraces or azonal groundwater soils of the valley bottom. Considerable areas of open grazing land, much of it steep and rough, lie adjacent to the Similkameen bottomland (49).

(a) The Princeton-Nicola-Kamloops Depression

The Princeton-Kamloops Depression, a trough of some definiteness, developed in Tertiary times, and extending from a point close to the American border south of Princeton, north for 150 miles to Kamloops, is only 20 to 30 miles wide. The depression is drained successively by streams which only run for a short distance along its axis, the Similkameen, the Nicola and the Thompson. Lakes are formed in nearly all parts of the depression; two, Nicola and Kamloops Lakes, are over ten miles in length. At least three basins, probably initiated in the late Tertiary, are recognizable along the depression; one centers around Princeton (2500 ft.) in the south, another around Merritt and another around Kamloops. "Soft" rocks of Carboniferous, Cretaceous and Tertiary ages are associated with each basin, a contributing factor no doubt for the more or less subdued local basin topography. In each basin, as Matthews (47) has described, seried lakes formed in late Pleistocene times as melting ice successively, dammed one narrow basin outlet or another. Associated with the lakes long since gone, were tremendous unconsolidated deposits in the form of

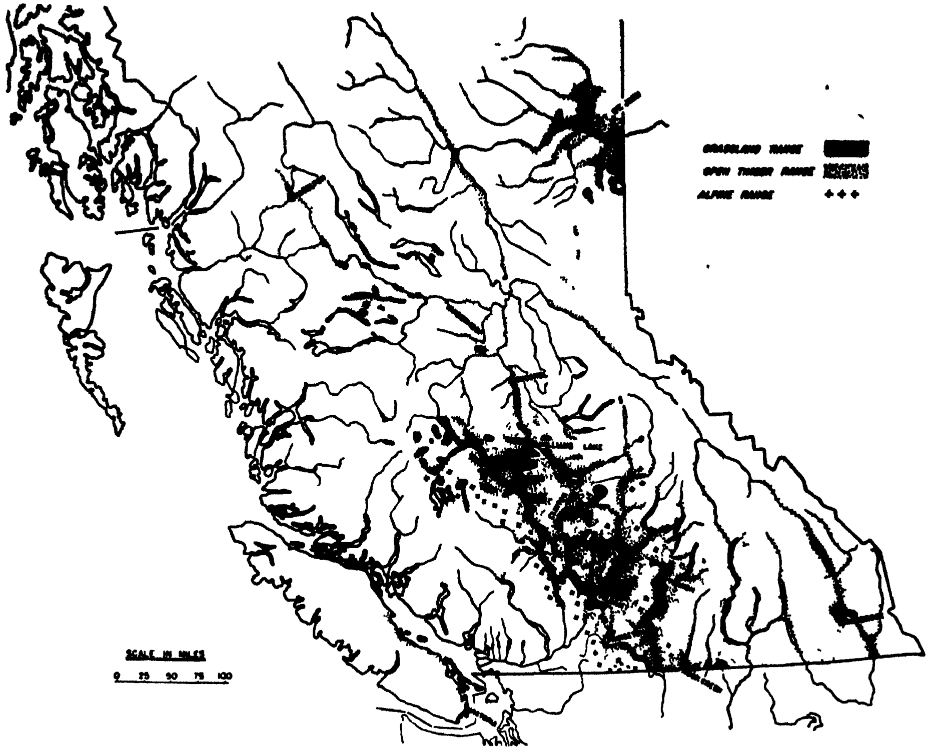

FIGURE 9. Livestock in British Columbia are ranged largely over the interior belt of plateaux: parts, also, of the coastal trench, southern Rocky Mountain Trench and Peace River plains support a limited range industry.

abandoned fans, flood plains, stream channels and terraces. In the basins large areas of relatively stone-free till exist. Associated with the basins are some of the largest areas of open grassland of good topography in the province. Soil zones in the area are closely related to altitude and aspect and are similar to those in the Okanagan.

The Princeton basin is the highest and smallest of the three basins along the depression. The agricultural usefulness centers around a sharply rolling native grassland of 110,000 acres and extensive timber and alpine range. A limited arable agriculture, some irrigated, is found on the 30,000 acres of arable terrace and alluvium.

The Nicola Basin, somewhat lower in elevation, also supports a grazing economy associated with one of the largest areas of open grassland in the province. An estimated 50,000 acres of land in the basin is capable of cultivation; 500,000 acres is in open grassland (49).

The largest basin, the Kamloops basin, has the lowest elevation (1200 feet) and the roughest topography. Its limits are difficult to define. One major river, the Thompson, has cut a deep transverse trench across the basin and the North Thompson, flowing perhaps as a continuation of the Princeton-Kamloops depression, enters the trench from the north. There are in the basin some 40,000 acres of cultivatable land and some 150,000 acres of open grazing land (18, 60, 63).

(f) The Western Highlands

The Western Highlands (11) lying between the Princeton-Kamloops depression and the eastern margin of the Coast Range extend northward from Coquilhalla Pass to obtain a maximum width of 70 miles at latitude 51°. Generally speaking the upland surface is well preserved in spite of high elevations (maximum 7500 feet). The deep narrow V-shaped gorges of the Nicola, Thompson and Fraser Rivers penetrate the Highlands. Apart from the limited grazing lands on the upland surface the agriculturally useful lands in this section are confined to these gorges. Again terraces of late Pleistocene age cling to the steep valley walls above river level and upon their surfaces there is some arable land. Irrigated haylands are found on scattered benchland, seldom over 1000 yards wide along the Nicola, the Thompson and along the Fraser as far south as Boston Bar. At Lytton, where the Thompson and Fraser are confluent and at Lillooet 40 miles north on the Fraser, the terraces support an intensive agriculture on several thousand arable acres. Also in the Highlands are the wild hay meadows of the Coldwater, Tulameen and other valleys.

(g) The Cariboo-Chilcotin Plateaux

The physiographic division of the remainder of the Interior Belt of Plateaux in Central and North Central British Columbia presents some difficulty and until such time as more information is available it seems best to treat that part of this belt lying north of the Thompson River as a unit. A tentative recognition of the two divisions—the Cariboo-Chilcotin and the Nechako Plateaux—has long been maintained (61). The division rests primarily upon a poorly defined "East-West" highland north of the Chilcotin River and south of the Nechako River—made up of the Telegraph Range and other ranges to the west—with summit elevations rarely over 5000 feet. The highland rises some 2000 feet above the general elevation of the Nechako plateau but only 500 to 1000 feet above the Cariboo-Chilcotin plateau.

From rounded summits of from 5000 to 6000 feet North and West of the Thompson and North Thompson Rivers, the plateau surface trends strongly north-westward widening perceptibly at latitude 52° as the Coast Range "swings" with a strongly westerly component. In latitude 54°, in the valley of the Fraser near Prince George the plateau surface merges with the floor of the Rocky Mountain Trench. Drainage, except for the western fringes of the surface, is by the Fraser River which, in its southward flow, cuts diagonally across the plateau surface. At Prince George the valley of the Fraser, while narrow, is but a few hundred feet below the general upland surface but as it flows southward the course becomes more canyon-like and below Gang Ranch where it begins to parallel the Coast Ranges the plateau surface is 2000 feet above river level. Tributary streams cross the plateau from the east and west; as for the major streams, the Chilcotin, Blackwater, Quesnel and Nechako, their canyon or valley development closely parallels that of the Fraser. Smaller tributaries, such as the San Juan River, however, often cross the plateau surface on a gentle gradient to plunge steeply to the major streams near their confluence.

Viewed broadly, the plateaux presents a comparatively uniform surface, broken chiefly by the deep cuts of the major streams and in general reflects the undisturbed character of the Tertiary volcanics which underlie

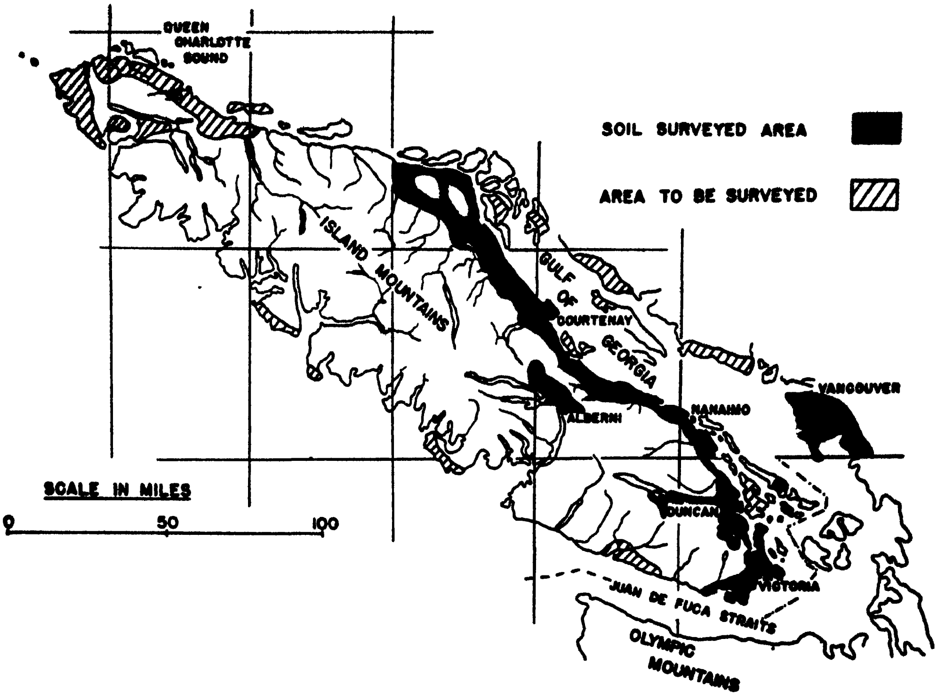

FIGURE 10. Areas on Vancouver Island within which arable land may be found.

70 per cent of the area. A study of the micro-relief, however, reveals the presence of large numbers of moraine dammed lakes and sloughs, drumlins, eskers, abandoned stream channels and alluvial fans. In some places glacial till is thick and over large areas it is thin. In short, the effects of the Pleistocene ice in scouring, depositing, laking and washing are much in evidence over the plateau surface.

In the Cariboo and Chilcotin, elevations are comparatively high over the plateau surface—3000 to 4000 feet (Figure 3). Most of the upland, especially at the higher elevations, is lightly forested (less than 5000 M.B.M.) and is lake dotted. At lower elevations, close to the major drainage channels, open grasslands occur. Terraces with gentle surface gradients and steep fronts occur as prominent features of the major valleys such as the Fraser and Chilcotin. High elevation, rough microtopography and the great development of light or rocky soils combine to limit agricultural land. Arable areas are scattered and confined chiefly to the major valleys, terraces and grasslands. Upland elevations are generally too high for successful farming. Some 70,000 acres are under cultivation; much of it is irrigated. On the west bank of the Fraser there are some 700,000 acres of open grazing land, on the east bank, 500,000 acres. Inasmuch as ranching is the principal agricultural enterprise, arable land is devoted largely to hay production. Natural meadows, often of considerable size, are abundant in nearly all parts of the upland. Brown soils, characterizing the areas of low grassland, are found only at elevations below 2000 feet in the major trenches. Shallow black soils characterize the more abundant upper grassland on the plateau surface. Grey-wooded soils characterize much of the forested area.

(h) The Nechako Plateaux

In the late Pleistocene, ice undoubtedly lay in the valley of the Fraser at points south of Prince George, such as Soda Creek and Jesmond long after it had departed from the upland surface of the Nechako plateau. A great glacial lake or lakes must have extended from the ice dams, certainly from Soda Creek northwards up the Fraser almost to present day Peace River drainage and far west to the present site of Fort Fraser to fill old Tertiary basins. An almost continuous lake or chain of lakes over two hundred miles in length may have been created. To-day the presence of the late Pleistocene laking is recorded in the great thicknesses of lacustrine quasi "white silts" spreading broadly over the Nechako and Upper Fraser Basin. Adjacent to and sometimes mingled with the finer lacustrine materials are broad plains of gravel, sand and till, especially to the north. While ice blocked the present drainage, the overflow from the lakes must have taken place to the northward into the Rocky Mountain Trench and Peace River drainage. Well developed lakeshore features are found at elevations up to 2700 feet. The principal surface varies from 2000 feet to 2400 feet. As the ice block to the south melted by stages, drainage was resumed down the Fraser River Valley. The streams of to-day, the Nechako, Cottonwood and Fraser along with their tributaries, cut rapidly through the soft strata, break the lacustrine surface with sharp canyons 100 to 500 feet in depth. The uniformity of the surface is yet largely retained, however, and to-day constitutes one of the largest topographically uniform areas in British Columbia (3, 4, 37).

The Nechako basin and plateau extends in long fingers northward beyond Stuart Lake and well into the mountains of Omineca System; it merges imperceptibly over a low pass (Summit L.) with the Peace River drainage in the Rocky Mountain Trench. The surface breaks sharply with the outlines of the Columbian Mountain system and the Telegraph Range in the southeast and gradually with the rolling hills of the Lake Country (Francois and Ootsa Lakes) to the south. The broad Bulkley Valley and Babine Valley (lake filled) to the northwest are separated from the basin by low passes.

In North Central British Columbia agriculturally useful lands are also found in the Bulkley Valley and in the lake country areas adjacent to the Nechako Basin but hardly part of it. The Bulkley Valley lies between two ranges flanking the Coast Range, the Bulkley and Babine Mountains and is probably, in part at least, structural in origin. The valley floor, of moderate relief rarely totalling 1000 feet, presents a varied array of tills, lacustrine bottoms, terraces, alluvial fans, eskers and moraines. An appreciable fraction of the bottom is composed of deposit of sufficient uniformity and fineness to be agriculturally useful.

Subdued topography is also associated with the lower slopes and inter-lake valleys of the lake country. Ice and water have etched long narrow fiord-like valleys across the subdued surface of the Tertiary lavas.

Over 1,500,000 acres of arable land have been surveyed in the Nechako Basin, Bulkley Valley and adjacent lake country. Most of it is lightly timbered and most of it is characterized by grey-wooded podsols. Some shallow black grassland soils have developed, principally west of Vanderhoof

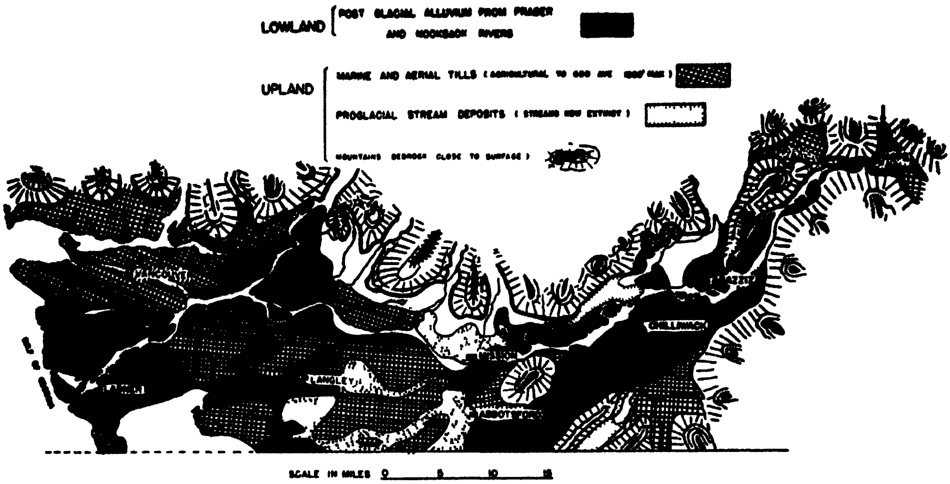

FIGURE 11. The lower Fraser Valley. most of the area shown is agriculturally useful.

in the Bulkley Valley. Only some 300,000 acres of open grazing land, widely scattered, is estimated for the area (21, 49).

(i) The Interior Plateaux in Northern British Columbia

While the Interior Plateaux Belt finds a counterpart north of the Nechako Basin (34, 77, 78) lands even for gardens are very limited. Some tundra-like grassland is found on land on low relief at elevations of 3500 to 4000 feet in the lee of the Coast Range. Around Atlin, apparently, on soils of lacustrine origin laid down in one of the great chain of late Pleistocene lakes which extended from British Columbia far into the Yukon, a few hundred acres of arable land have been developed. Terraces above the town of Telegraph Creek on the Stikine and Tanzilla Rivers may have a limited agricultural usefulness.

THE COLUMBIAN MOUNTAINS

The Columbian Mountains rise from the Interior Plateaux on the west and extend to the Rocky Mountain trench on the east. The southern limits of the system, across the International Boundary, are hard to define. On the north, the system fades out about the latitude of Prince George into a broad plateau where the Interior veldt and the Rocky Mountain trench are confluent. While others (17) have properly subdivided the Columbian Mountains, there is a certain unity of topographic form throughout the system. The ranges are characterized by either flat topped summits or horns which may surpass elevations of 10,000 feet, in several sections. The effects of the Pleistocene and recent glaciation are shown by numerous cirques, tarns, and deep U-shaped valleys which often show the over-deepened long profiles of valley glaciation. An outstanding character of parts of the system is the development of low passes between parallel valleys often large out of all proportion to the streams which occupy them. The rocks of the system are principally highly metamorphosed sedimentaries and volcanics, probably of Pre-Cambrian Era, intermixed with considerable areas of granitic, batholithic elements (27).

(a) The Grand Forks Area

Limited areas of agricultural land are found in some of the great longitudinal and transverse valleys of the system. On the west, in valleys occupied by the Kettle River especially at Grand Forks there are pro-glacial alluvium and terrace soils under irrigation. Limited areas of open and semi-open valley sides and bottom are used for cattle range and hay meadow. Around Grand Forks (elevation 1800 ft.) is found the largest single acreage of arable land in the West Kootenay with about 20,000 acres at present under intensive cultivation.

(b) The Columbian (Arrow Lakes) Trench

The Columbian Trench (Figure 1) striking about north and south, from the Rocky Mountain trench in the north to the lava plains of Washington State in the south, is occupied by the Columbia River and the Arrow Lakes. The trench is seldom more than one or two miles wide and is bounded throughout by high mountains. It is lake-filled for more than one-third of its length; bottom elevations run around 1500 feet. Arable land is found in interrupted pro-glacial alluvium and terrace from Revelstoke to Arrowhead and Sidmouth at the northern end of the Arrow Lakes for a distance of 30 miles. Scattered narrow terraces, usually only a few hundred yards wide, cling to the steep walls along the Arrow Lakes and support some orchards. In the vicinity of Castlegar where the valleys of the Columbia and Kootenay meet terrace and alluvium permit the settlement of a few thousands of acres.

(c) The Purcell (Kootenay) Trench

The eastern portion of the Columbian mountains is again partitioned by a fairly well defined trench, the Purcell (or Kootenay) trench. This feature is initiated in the north by the valley of the Beaver River which debouches into the Columbia River in the Rocky Mountain trench. The trench is occupied successively by the Duncan River, Kootenay Lake and Kootenay River (51). Several thousand acres of arable land (the Lardeau area) some distance from the principal transportation systems and largely undeveloped, are found along Trout and Duncan Lakes and at Argenta at the northern end of Kootenay Lake. Narrow Benches at Kaslo and other scattered points along Kootenay Lake support an arable agriculture. At Creston, elevation 1700 feet, at the southern end of Kootenay Lake are 25,000 acres of alluvium (19,500 acres reclaimed) and 5000 acres of intensively farmed terrace. Many other narrow valleys in the Columbian system have small and scattered acreages of arable land; of these the Slocan valley, largely lake-filled, located between the Purcell and Columbia trenches and paralleled by them, the Pend Oreille, Salmo and Beaver valleys, and the Seymour valley at the northern end of a fiord arm of Shuswap Lake should be mentioned.

(d) The North Thompson Trench

Important acreages of arable and grazing land are in use along the narrow valley of the North Thompson River for 100 miles from Kamloops to Vavenby along the main line of the Canadian National Railways. The lands, however, are confined to narrow terraces and alluvial bottom which are frequently broken by rocky outcrops.

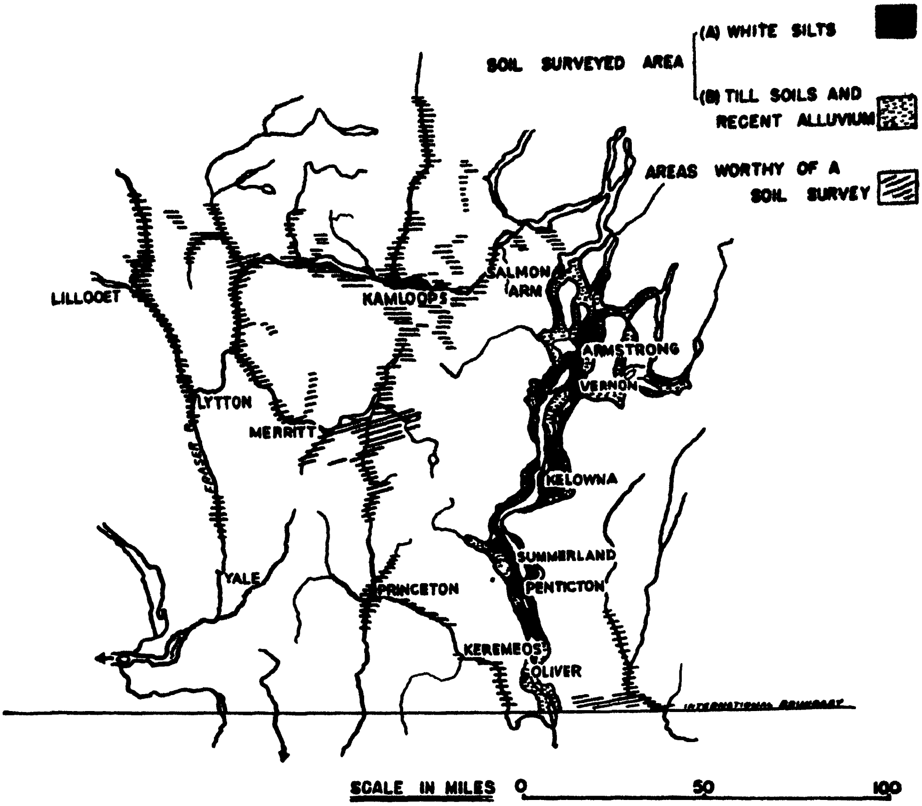

FIGURE 12. The Okanagan-Thompson Valleys.

THE ROCKY MOUNTAIN TRENCH

From Flathead Lake in Montana to the Liard River and beyond, a distance of more than 900 miles, there runs a narrow, wonderfully straight depression lying between the Rocky Mountains on the east and the rest of the Cordillera on the west, termed the Rocky Mountain trench. Unique among the physiographic features (59, 60) of the globe for its persistence the trench is in turn occupied by the headwaters of the Flathead, Kootenay, Columbia, Canoe, Fraser, Parsnip, Finlay and Kechika Rivers. The trench bottom over most of its length is only one or two miles wide but in places, notably in the south around Cranbrook and in the north around Finlay Forks, it may exceed ten miles in width over considerable distances. Around Cranbrook the valley bottom elevations may drop slightly below 3000 feet, but at Finlay Forks elevations average 1000 feet lower. East of the trench the west margin of the Rocky Mountains rises abruptly, 6000 to 8000 feet in a wall of well stratified rock. Bold ridges often 8000 feet high, with deeply incised valleys between, rise in a continuous array along the western side of trench to present a striking contrast between the two sides of the trench over much of its length.

(a) The Cranbrook-Windermere Area

Two agricultural areas worthy of note, the Windermere Valley and the Cranbrook district, are developed in the trench between Golden and the International Boundary, a distance of 175 miles. The general relief of the broad bottom in this section appears to be broken only by a few foothills. Closer examination reveals a surface broken frequently by conspicuous moraines, kettles, eskers, and terraces of silts, sands and gravels. "During the Pleistocene the area was covered by a continental ice sheet which, as it disappeared, resulted in a stage of alpine glaciation." During both stages acute erosion by ice took place only at high elevations (8, 53, 53). The final disappearance of the ice in this part of the trench took place in stagnation. In recent times there has been much reworking of the glacial materials. Good agricultural soils, then, are scattered. While they are topographically suitable for agriculture, many terrace soils are coarse and excessively well drained. Conversely, poor drainage characterizes much bottom land and without reclamation it is useful only for wild hay production. The southern part of the trench supports an open vegetation and a small range industry has developed. On what appear to be loessial soils around Cranbrook, a dry farming agriculture has developed. More extensive pro-glacial laking around Windermere, has resulted in fairly extensive development of terraces and bottomlands of white silts which support a mixed agriculture. The terraces are least developed at 2700, 2800 and 3000 feet on both sides of a central depression largely lake-filled about three-quarters of a mile wide (67).

(b) The McBride Area

Hay meadows are common along the Fraser River as it flows in the Rocky Mountain trench towards Prince George. At McBride, 150 miles east of Prince George, several thousand acres of raised delta and alluvio-lacustrine soils are used for mixed farming.

(c) The Finlay-Parsnip Area

Terraced lacustrine materials of fairly fine character are reported to fill a very large area of the Rocky Mountain trench occupied by the lower reaches of the Finlay and Parsnip Rivers (1, 75). The Peace River drainage was apparently resumed in Pleistocene times before the Fraser drainage and silt-laden waters from Central British Columbia no doubt flowed into the Rocky Mountain trench. It would appear, too, that considerable laking occurred in the valleys of the Finlay and Parsnip due to ice damming in the upper Rocky Mountain reaches of the Peace River (6). Possibly for a time the spillway of the pro-glacial lake was Pine River Pass. In any event, there are several hundred thousand acres of fairly well sorted lacustrine soils in the Rocky Mountain trench at this latitude, some of which may become agricultural if difficulties of transportation and shortness of growing season are overcome.

THE ROCKY MOUNTAINS

The Canadian Rocky Mountains "are bounded on the west by the Rocky Mountain trench and on the east by the foothills and the Great Plains (72)." Originating in Montana (or perhaps, some might believe, farther south) the range persists in essential unity north to the Liard Valley. The chain presents few "breaks" along its length and few passes are below 5000 feet in elevation; in the vicinity of the Peace River, however, where the range is narrow (20 miles) the summits and passes are lower; Peace River Pass is but 1500 feet, Pine Pass, not quite 3000 feet. North of the Peace River summit elevations of over 9000 feet have been established; south of the Peace River lies Mount Robson (elevation 12,972 ft.), the highest peak in the Canadian Rockies, and many peaks over 10,000 feet in elevation are found in the range to the border. In aspect the range is quite different to the rest of the Cordillera in British Columbia which is largely vegetated and constituted of plutonics and highly metamorphosed sedimentary, volcanic rocks. In the Rockies "rugged peaks and precipices, gorges and valleys have been carved by erosion out of sedimentary formations of blue-grey limestone, dark shale, buff sandstone and quartzite. Clean-cut surfaces expose mountain folding and faulting so well that pressure from the west is clearly demonstrated as the origin of the structure" (82).

The Canadian Rocky Mountains will not support agricultural pursuits. They are quite unsuited for domesticated grazing animals such as may be found in the Swiss Alps. Certain grazing and browsing areas, however, are largely used by big game and a few mountain pastures in the south are used by range livestock.

THE TRAMONTANE PLAINS

The Tramontane Plains of northeastern British Columbia make up 10 per cent of the acreage of the province (1). Structurally and geologically they occupy a position similar to the plains of Alberta and are integral parts of the Great Plains region, the heartland of the North American continent (56, 69, 70).

When compared with other parts of the political province the tramontane area is conspicuous in the uniformity of its surface. However, physiographic subdivisions based on topographic and stratigraphic considerations may be recognized.

(a) The Foothills Section

A foothills section, fifteen to twenty miles wide, along the lee of the Rocky Mountains, consists of hills whose flat-topped concordant surfaces slope easily to the east. Bedrock is, almost entirely, gently folded Cretaceous shale and sandstone (6, 45). In the vicinity of the Peace River canyon maximum relief is from 1500 feet to 5000 feet above the sea and in the vicinity of the Nelson and Liard Rivers very little less.

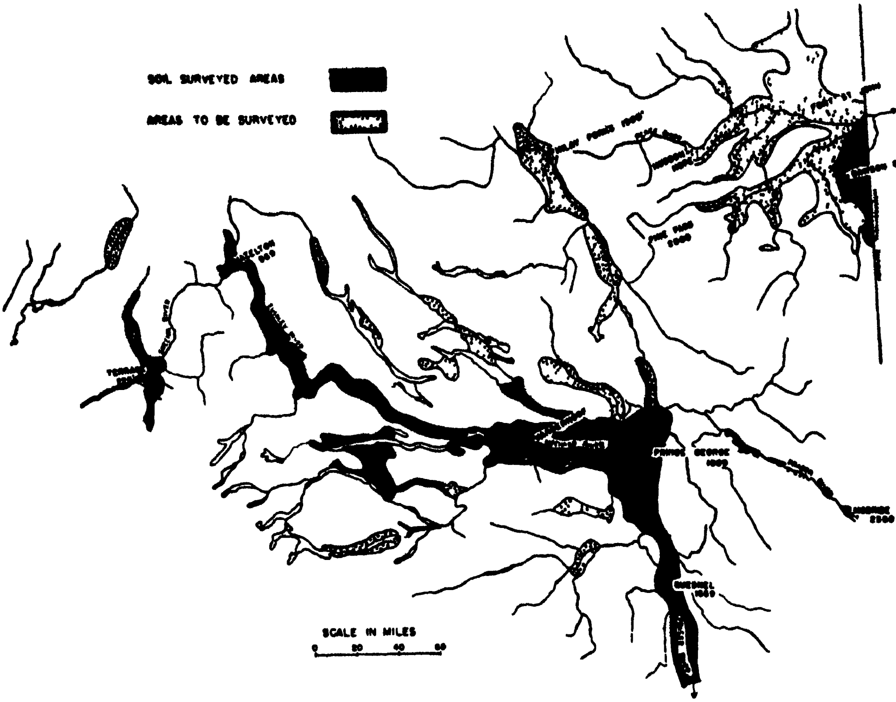

FIGURE 13. North Central British Columbia and Peace River areas showing areas within which arable lands are located.

Agriculturally useful land is found in the foothills section only on the terraces which border the Peace and Liard Rivers. Some of the terraces, as found around Hudson Hope on the Peace River, are broad and continuous for several miles; they are usually well preserved up to elevations over 500 feet above the river. A limited agriculture has been developed on a few terraces near Hudson Hope and Gold Bar.

(b) The Peace and Nelson Basins

Two great basins, 500 to 1000 feet below the mean level, may be recognized in the tramontane area of northeastern British Columbia, the Peace River basin in the south and the Nelson basin in the north. Agricultural interest centers in the broad lands which slope gently towards the major streams, the Peace, the Nelson and a few of their tributaries (56).

The principal agricultural soils of the Peace River basin in British Columbia are found at elevations from 1800 feet to 2400 feet. Maximum elevation for agricultural lands may be liberally placed at 3000 feet. The lower elevations, around 1000 feet, in the Nelson basin compensate somewhat for its more northerly location and some of the well drained benches with southerly exposure close to the major streams, the Musqua, Prophet and Nelson Rivers may eventually be useful agriculturally. Underlying the basins are sedimentary rocks of Cretaceous age which thicken from east to west (2); quaternary gravels, silts and clay mantle these. In the Peace basin and probably also in the Nelson basin pro-glacial lakes developed in Pleistocene time between the Keewatin ice front on the east and the foothills on the west. Some glacio-fluvial sediments in and around the basins

came from the Shield rocks to the east. The lacustrine, outwash, and flood plain origins of the soils are much in evidence but their genesis has not received careful study. Limited areas of shallow black and degraded black soils occur in the Peace basin. Some of these at Pouce Coupe, Dawson Creek and Fort St. John, prior to settlement, were in open grassland and parkland. By far the greater area is characterized by grey wooded podsols (23).

(c) The River Valleys

The Peace River and its tributaries in British Columbia are deeply entrenched in steep walled valleys 600 or more feet below the mean basin level (56). The deep valleys, a recent erosion feature, constitute important barriers to easy development of the agricultural soils of the basin. Underdrainage, too, is excessive in the lighter soils near the breaks high above the rivers and water shortage exists in places. In the Fort Nelson area the major streams are in places entrenched 400 feet. Drainage, however, is sufficiently impaired to create muskeg conditions over considerable areas.

(d) The Uplands

Semi-continuous uplands, flat-topped, generally covered with relatively stone-free till, make up a large fraction of the lands of the tramontane area. Some of the elevations dividing the Peace and Nelson basins approach 4000 feet. Tertiary feature remnants are probably represented in the upland surface (69, 71).

DISCUSSION

Some principal impressions to be gained from the foregoing account of the provincial physiography are that British Columbia presents an extremely rough, predominantly mountainous aspect, that there is a "limited" amount of arable land, and that the arable land is, in the main, remarkably diffuse. Daly (17) writing of the southern border lands of the province, has said that no other mountains both so continuously rough and so wide exist in the world. No verbal description can quite convey the picture of the uneven land surface. Good physiographic maps assist materially (68, 78). Aerial photos of the political province which also may be used to gain suitable impressions are now available in excellent libraries (76, 78). Only a very few representative air photos could be included in this paper (Figures 2-5).

Elevation above the sea is of utmost importance in appraising the arable lands of British Columbia. Nearly all tillable soils will be below the 3000 feet contour (Figure 6). Certainly the growing season is so short at higher elevations north of latitude 52° that the development of little but gardens is permitted. Admittedly at Rose Hill, Alkali Lake and Bridesville, all points on the Interior Plateau surface, dry farming is practised in a limited way at elevations above 3000 feet. Reference to Figure 6 which shows the pattern of the distribution of lands below this contour, about 30 per cent of the provincial total, is an important step in showing the extent and distribution of arable lands.

Figure 8 shows areas of the province which are topographically uniform enough to permit an arable agriculture. The pattern is essentially that by Whitford and Craig (68), with modifications, and delimits about 10 per

cent of the total acreage of the province. Lands outlined, of course, are not wholly arable but have a uniform macrotopography and elevations and latitudes which will generally permit at least cereal culture. Parts of these areas, however, will possess poorly drained soils, porous members, non-irrigable soils or a microtopography too rough for the plough. Principal agricultural areas, it also may be seen, are associated with the non-mountainous physiographic divisions, the Coastal trench, the Interior belt of plateaux, the Rocky Mountain trench, and the Tramontane Plains.

Range lands are not limited by a 3000 feet contour; also grassland too rough for the plough and timbered lands may be used by range sheep and cattle. Figure 9 is an attempt to show the distribution and character of the range lands of the province. Grassland range is found at all elevations up to 4000 feet, timber range to 6000 feet, and alpine range to 7500 feet depending on latitude and exposure. Most of the range land, it may be noted, is associated with the Interior belt of plateaux; limited range is found in the southern Rocky Mountain trench, in the Kootenay and Peace River Districts and on Southern Vancouver Island.

Maps (Figures 10, 11, 12, 13) of the four principal agricultural areas of British Columbia show some details of physiographic and distributional nature not shown in Figure 3. It seemed worthwhile to emphasize in Figure 11 the pattern and genesis of the lowland and upland soils of the Lower Fraser Valley. Planning for the best use of these important soils must take careful account of these features, correlated as they are with moisture supply, drainage, and productivity. On the map of the Okanagan-Thompson area (Figure 12) it seemed desirable to emphasize the distribution of the white silts to which previous reference has been made for it is on these that the valuable tree fruit industry has developed.

Many attempts have been made to assess the total acreage of arable and range land in British Columbia (1, 68, 75). One of the most recent and most comprehensive is that of the forester, Mulholland (49) who places the estimate at 4,250,000 acres or 2 per cent of the total provincial area. An additional 2 per cent or 4,700,000 acres are in open grassland and park suitable for range. No estimates are given for timber range but this is a little consequence, since lack of open grassland is distinctly limiting the greater use of this range class. Out of a total of 234,400,000 acres in the province, Mulholland finds 154,700,000 acres or 66 per cent unsuitable for forestry or agriculture.

One can readily see that disposition of the arable lands of British Columbia on physiographic bases and on total acreage does not compare favourably with their disposition in the Prairie Provinces and Eastern Canada. Valuable though the physiographic approach may be in showing the distribution, size and shape, and in indicating the nature of arable lands, non-physiographic features should, of course, be considered also in assessing their value. Some of the lands enjoy Canada's more favourable climates. All bear relationships to large consuming populations in south-western British Columbia whose agricultural needs are scarcely met by the lands within the province. Important mining, fishing, forestry and manufacturing industries are related to the arable lands. Nearly all arable lands, too, are closely associated with the major lines of transportation.

Another impression to be gained from a physiographic study of the agricultural areas of British Columbia is the very great importance of the Pleistocene and post-Pleistocene geology in the soil genesis. Pleistocene ice covered nearly all of the province and profoundly modified its topography. Virtually no arable soils have developed *in situ*. Most soil profile development has occurred within the last 20,000 years (73). Great pro-glacial lakes with their associated terraces and bottom silts played a major role in the deposition of arable soils. Glacial streams, now much reduced or no longer extant, resorted till and loess to build fans and deltas on which farms may be located to-day. Alluvium deposited in deep waters along the coast and subsequently elevated with the rising post-Pleistocene shoreline has yielded plowlands on Vancouver Island and the Lower Fraser Valley. More attention by geologists and others to the genesis of the superficial deposits over the province is warranted.

While the importance of physiographic controls has been emphasized occasionally for British Columbia, few persons have yet grasped their profound importance in meaningful descriptions of the provincial soil, climate and biota. Our particular interest in this paper has been to relate the agricultural lands to the physiographic features; our interest has aimed, not at finely delimiting our arable acres and ranges, but at designating their probable location and emphasizing their distribution—their macro characteristics. The Dominion-Provincial Soil Surveys and the Provincial Land Utilization Surveys will provide, before many years have passed, a more comprehensive description of the agricultural soils. Few, however, will deny the need for re-emphasis (1, 5, 12, 20, 26, 29, 43, 51, 66, 68, 74, 75) of physiographic features at this time when much energy is being devoted to proper land use, and conservation and when attempts are being made at more comprehensive accounts of our climate, and biota. Following the physiographic approach, appraisal of our lands and farm problems will, we hope, be made easier for the novice in British Columbia agriculture.

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EQUINE PREGNANCY DIAGNOSIS BY BIOLOGICAL AND CHEMICAL TECHNIQUES[1]

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INTRODUCTION

Equine pregnancy has been determined by several biological and chemical methods, the former depending on the early presence of gonadotropin in the blood, the latter depending on the later appearance of estrogen in the urine. Cole and Hart (1), using both the ovarian weight and the vaginal smear of the immature rat as criteria of pregnancy, report that blood specimens from mares under test should be taken between the 45th and 120th days of pregnancy. Mayer (2), applying the ovarian weight test, considers that the optimum time for testing blood serum is between the 50th and 90th days. A chemical procedure developed by Cuboni (3) depends on the presence of estrogen in pregnant mare's urine. Most workers consider this test to be applicable after the 120th day of pregnancy.

Both biological and chemical methods have been applied to establish the percentage of successful matings in a series of one hundred and nineteen mares. Circumstances prevented the testing of all the mares by both methods, as planned, but sufficient information has been obtained for a comparison of the relative reliability of the two methods. Foaling data provided confirmation of the tests. The specimens for examination were selected at the optimum stage of pregnancy for each test.

PROCEDURE FOR BIOLOGICAL TEST

Blood from the jugular vein was first allowed to clot and then was chilled overnight. The serum was decanted into sterile bottles containing merthiolate in such an amount that the preservative concentration was 1-10,000. This precaution was taken because some of the blood specimens were collected at a considerable distance from the laboratory. To ensure that the presence of merthiolate would have no effect on the test a preliminary trial was made on a known sample of pregnancy serum using aliquots with and without preservative.

Rats from 21-23 days of age were injected subcutaneously with 2 ml. of the serum. Two test rats and one control were used for each serum specimen. The rats were sacrificed after 96 hours and a 50 per cent increase in ovarian weight was considered to be a positive reaction. The presence of cornified cells in vaginal smears confirmed the positive diagnosis in every case.

[1] Contribution No. 164 from the Division of Chemistry, Science Service, Department of Agriculture, Ottawa, Canada.

PROCEDURE FOR CHEMICAL TEST

Urine samples were received in 2 oz. bottles containing 2 ml. toluol to inhibit bacterial decomposition. The test for pregnancy, as outlined, was essentially that of Cuboni (3) with slight modifications by Cole and Hart (1).

Acidify 5 ml. of urine with 1 ml. of concentrated hydrochloric acid. Place in a boiling water bath for 10 minutes, cool and extract with 6 ml. of benzol. Dry 3 ml. of this extract at 60° to 80° C. Add 4 ml. of concentrated sulphuric acid to the residue and warm in a water bath to 70° to 80° C. Read in 10 minutes by reflected light.

To ensure that the green fluorescence indicative of a positive response was due to estrogen alone, 1 ml. of water was added to eliminate any green colour due to the presence of sterols. Negative specimens under this treatment are reddish brown.

RESULTS

The survey for pregnancy comprised one hundred and nineteen mares. A total of ninety-six samples of urine and forty-seven samples of blood were obtained. As twenty-four mares were diagnosed by both biological and chemical methods and since foaling records were available it was possible to assess the relative reliability of the two methods employed for diagnosis. Comparative data for both methods are shown in Table 1.

It may be noted in Table 1 that the biological and chemical techniques gave 91.5 and 92.7 per cent correct diagnoses respectively. Mayer (2) suggests that the error in diagnosis based on serum examination need not be over 5 per cent while Cole and Hart (1) suggest the limit of 2 per cent. According to the latter authors the Cuboni test on urine may give 1-5 per cent false diagnoses. The comparatively large error reported in the present survey was due to the incorrect negative diagnosis of seven mares. It may be seen in Table 2 that four of these animals were examined by both methods.

TABLE 1.—A COMPARISON OF BIOLOGICAL AND CHEMICAL METHODS FOR EQUINE PREGNANCY DIAGNOSIS

Diagnosis	Biological (serum) test		Chemical (urine) test	
	Number of mares examined	Days pregnant	Number of mares examined	Days pregnant
Correct negative	36	62–127	72	137–251
Correct positive	7	59–106	17	127–271
Incorrect negative	4	65–85	7	166–215
Incorrect positive	0	—	0	—
Total	47		96	
Error in diagnosis	(%) 8.5		(%) 7.3	

Total number of mares examined, 119.

TABLE 2.—ERROR IN EQUINE PREGNANCY DIAGNOSIS

Biological (serum) test			Chemical (urine) test		
Horse No.	Interval (days)	Diagnosis	Interval (days)	Diagnosis	Foaling record
92	65	Negative	166	Negative	Foaled
95	85	Negative	166	Negative	Foaled
117	85	Negative	213	Negative	Foaled
96	85	Negative	215	Negative	Foaled
43			182	Negative	Foaled
27			198	Negative	Foaled
114			208	Negative	Foaled

The errors in diagnosis are not apparently related to the times at which the specimens were obtained. The collection times for both serum and urine fall well within the time interval for the other mares in the series which were correctly diagnosed. One possible explanation for such error might be that the hormone levels of these particular animals were too low at the time of collection to give a measurable reaction. Hormone levels in mares are known to be subject to wide variations.

A study of twenty-four mares which were tested by both methods shows that all mares, including the four which were incorrectly diagnosed, gave identical responses in each test. It would appear that the error is not inherent in the methods but rather it is due to some peculiarity of these particular horses.

SUMMARY

A pregnancy survey involving one hundred and nineteen mares was based on diagnosis by biological testing of serum or by chemical examination of urine. Some mares were tested by both methods. Collections were made at the optimum stage of pregnancy for each method and foaling records were used to determine the reliability of the methods.

All positive diagnoses were confirmed.

Incorrect negative diagnoses by biological and chemical methods were made in 8.5 and 7.3 per cent of the tests, respectively.

Mares which were examined by both methods gave identical responses for each test.

While the biological procedure provides an early diagnostic test the chemical procedure, because of its economy, simplicity and comparative reliability, is preferred for pregnancy confirmation.

ACKNOWLEDGMENT

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MOISTURE DETERMINATIONS IN THE COMPARATIVE TESTING OF FORAGE CROPS FOR HAY YIELD[1]

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INTRODUCTION

Wherever forage crop varieties are tested for comparative yields of hay it is the general practice to sample the green material for moisture content at the time of cutting. When these tests are made up of small, randomized plots one of the common methods of sampling consists of taking one or two moisture samples per plot, usually one to two pounds of green material in size, drying to oven-dryness and calculating the percentage dry matter of each sample. On the basis of this determination the green yield per plot is converted to dry yield per plot which is later expressed in terms of tons or pounds of hay per acre. When in terms of hay yield per acre it is necessary to adjust the yield from absolute dry matter to include a certain amount of moisture, usually 12 to 15 per cent.

This procedure requires considerable equipment and a great deal of time. At many experimental stations proper ovens for drying large numbers of samples are often not available and thus some improvisations have to be made. At the Dominion Forage Crops Laboratory, Saskatoon, Saskatchewan, the electrically heated drying oven will hold only 45 samples at one time. Each lot of samples must remain in the oven a minimum of four hours, at a temperature of 212° F., in order to reach a constant weight. During the haying season, when as many as 2500 moisture samples are taken, it is necessary to have the oven operating for several weeks.

It would therefore seem advantageous to investigate the possibilities of eliminating or at least reducing the number of moisture determinations. Thus this study is an attempt to determine whether simplified moisture sampling techniques could be used without sacrificing the accuracy of yield comparisons.

LITERATURE REVIEW

A review of the literature shows that there are differences in opinions among various investigators as to the necessity of moisture determinations in comparative tests of forage crops for hay yields. McRostie and Hamilton (3) compared the relative forage yields of several plots of grass and clover mixtures, as determined from field cured hay, green yields, and absolute dry yields. From these comparisons it was concluded that both green yield weights and field cured hay weights were unreliable, with green yields

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being the least accurate of all the methods. They stated that immediate drying of shrinkage samples appeared to offer the most accurate criterion for comparative tests. In studying the number of shrinkage samples per plot necessary to give accurate results they found that more than 2-pound samples per plot were not warranted.

Weihing (7), from a study of the dry matter content in alfalfa, found that strains and replicates could vary significantly in percentage dry matter, for any one date of cutting. From this study Weihing concluded that alfalfa forage yields based on green yields were inaccurate. In a comparison between air-dried and oven-dried samples it was found that samples that had been air-dried under cover were nearly as accurate as those based on oven-dry weights. He also stated that for a comparison between cuttings or between years air-dry forage yields should be reduced to a definite percentage of dry matter.

In contrast to the above investigations, Wilkins and Westover (9) studied the moisture content of Turkestan and Grimm alfalfa and found that the difference in water content of the two varieties was so slight that the yield data could be based on the green weights. The average water content from 19 comparisons of the two varieties was 72.2 per cent for Turkestan and 72.1 per cent for Grimm. On the basis of these results green yields were used throughout the remainder of their study, which was a comparison of Turkestan alfalfa and Grimm alfalfa on wilt-infected soils.

Wilkins and Hyland (8) made a rather extensive study of moisture sampling in alfalfa and red clover. They found that, although the water content of the alfalfa forage varied with the location of the plots, the differences were so small that yield determinations would have been essentially as accurate on a green weight basis without sampling. The results for red clover were found to be similar to those for alfalfa.

In a study to determine the number of samples required to measure accurately the water content of alfalfa and red clover forage, Wilkins and Hyland (8) found that either two or three samples per plot were required. They also found that different sizes of samples from 1 to 10 pounds gave similar results. In one of their ten tests the 1-pound samples were found to be inadequate.

Wilkins and Hyland (8) and Willard (10) studied the moisture content of forage at different times of day. Wilkins and Hyland found that alfalfa forage was approximately 2.25 per cent lower in water content at 1.30 p.m. and at 5.00 p.m. than at 8.00 a.m., and that red clover was about 3.75 per cent lower than at 8.00 a.m. when similar comparisons were made. Willard obtained somewhat similar results in that he found that the variation in moisture content, after the dew was off, was very seldom greater than 3 per cent, in any of the crops studied, and as such was not sufficient to warrant concern over the time of day of cutting.

MATERIAL AND METHODS

Yield data from previous years were used for the first part of this study. These data consisted of green yields, dry matter percentages, and dry yields of most of the comparative tests conducted at the Dominion Forage Crops Laboratory, Saskatoon during the years 1940 and 1941.

This period was chosen because moisture sampling at that time was on the basis of one 1.5-pound sample per plot. The tests chosen for this study consisted of crested wheat grass strain tests, brome grass strain tests, tests which included several grass species, alfalfa strain and variety tests, and tests of sweet clover strains, varieties, and species. Grass and legume mixtures were not included because it was felt that the differences between dry matter content of the grass and of the legumes were too large, and mixtures were not sufficiently uniform for them to be included in a study of this kind.

The yield data from each test were analysed using Fisher's Analysis of Variance as described by Patterson (4). The variance analysis of dry yield data, green yield data and dry matter percentage data were all determined for each test and comparisons were made.

Sampling Study

In the summer of 1946 a moisture sampling study was conducted to evaluate and compare several methods of moisture sampling. The samples taken consisted of two 1.5-pound samples, two 0.75-pound samples and three 0.5-pound samples from each plot. A minimum green yield of 6 pounds per plot was therefore required. Due to the dry conditions that existed during the spring and summer of 1946, resulting in low productivity of most of the forage plots, it was necessary to confine the study to three varietal tests. These included a test of seven grass species, a sweet clover variety test, and a brome grass strain test. In the latter case the number of 1.5-pound samples had to be reduced to one instead of two per plot.

Description of Variety Tests Used in the Sampling Study

The first test, seeded in 1945, was a comparison of seven grass species arranged in a randomized block design with six replicates. The grass species included were: *Elymus virginicus, Elymus canadensis: Agropyron elongatum, Agropyron glaucum, Agropyron desertorum, Agropyron cristatum,* and *Bromus inermis.* The plots were 20 feet long by 6 feet wide, each consisting of 13 rows spaced 6 inches apart. There was a 1-foot pass between plots and a 2.5-foot pass at the ends of the plots.

The second test, seeded in 1945, originally consisted of 14 varieties of sweet clover in a randomized block arrangement with six replicates. Due to poor stands obtained only six of the varieties were harvested. Plots were 20 feet long by 6 feet wide, each consisting of 13 rows spaced 6 inches apart. There was a 1-foot pass between the plots and a 2.5-foot pass at the ends of the plots.

The third was a test of brome grass strains from uniform grass nurseries, also seeded in 1945. This test consisted of 16 different strains of *Bromus inermis,* eleven of which were from the United States Department of Agriculture, three were other American strains, and two were Saskatchewan strains, arranged in a quadruplicate lattice design. Each plot was 15 feet long by 6 feet wide and consisted of six rows spaced 1 foot apart. There were no passes between plots but there was a 1.5-foot pass at the ends of the plots. For the purpose of this study this test was treated as a randomized block.

Sampling Procedure

Before harvesting the plots for hay 1 foot was trimmed off each end of each plot to eliminate border effect. Thus for a 20-foot plot only the remaining 18 feet were used in determining the hay yield. Cutting of the plots was accomplished by means of a small power mower with a 42-inch cutting bar with a pan attached, to collect the hay as it was cut. Only one swath was taken from each plot and this was down the centre of the plot. The cut material was rolled in a cotton sheet and taken immediately to be weighed and the net green weight recorded. The samples for moisture determinations were then weighed without delay and placed in Kraft paper bags. All of the moisture samples were kept separate and numbered according to plot, size of sample, and order of weighing.

All weights were taken on a set of Fairbanks-Morse combination pan and platform scales with an enlarged pan. The beam of the scale was counterbalanced to offset the weight of the pan and the weight of the cloth used to hold the sample. Thus the reading on the beam gave the net weight of the green material to the nearest quarter ounce.

From the field the moisture samples were taken to the laboratory where they were removed from the paper bags and placed unchopped in drying trays, which in turn were placed in the electrically heated oven. The thermostatically controlled oven, similar to that described by McRostie and Hamilton (2), was heated to 212° F. and kept at that temperature until the drying was completed. Before being allowed to cool, the individual samples were weighed, including the drying tray, on a Dayton balance. This balance records weights to the nearest sixteenth of an ounce. The weight of the tray in each case was then deducted to give the absolute dry weight of the sample. From these data the dry matter percentage for each sample was calculated.

The data thus taken provided a comparison of three sizes of moisture samples and also allowed several shorter sampling methods to be compared with the standard method of one 1.5-pound sample per plot. The sampling methods used will be described as they are presented in the section dealing with experimental results.

EXPERIMENTAL RESULTS

The Necessity of Moisture Samples

A summary of the green and dry yield data of the comparative tests of 1940 and 1941, together with the F values and significant differences from the variance analyses of these data appear in Table 1. For each test in Table 1 the strains have been arranged in descending order of dry weight yield, the highest yielding strain in each case being designated with the letter A. The corresponding green yield for each strain appears below the dry yield. Therefore when the green yields are not in descending order it means that a change in the ranking of the varieties has occurred due to the effect of moisture sampling.

Test number 1, Table 1, is the 1940 data from an alfalfa variety test which included six varieties of *Medicago media*. It is seen that the F value from the green weight analysis is very similar to that of the dry weight

analysis and neither one is significant. The ranking of the varieties on the green weight basis is A, B, C, E, D, F whereas the ranking on the dry weight basis is A, B, C, D, E, F. The yield differences between varieties D and E are very small and since there are no significant differences between varieties then this change in the ranking could be considered as being due to a chance variation.

Test number 1A is the same test as number 1 but the data is for the year 1941. Here again it is seen that the F values for strains from the variance analyses of the green and dry yields are very similar and both are non-significant. The ranking of the strains is the same for both dry and green yields.

Tests 3, 5, 6, 6A, 7, 7A and 8 all give the same type of results as the tests discussed above, that is, very similar non-significant F values for strains for both dry and green weight analyses, and little or no change in the ranking of the strains. Any changes occurring in the ranking of the strains in these tests must be relatively unimportant because the strains do not differ significantly in yield.

Test number 2 is the 1940 data from an alfalfa variety test which contained five varieties of *Medicago media.* The F values in this test are slightly different, with that for dry yields being 2.94 and significant at the 5 per cent level and that for green yields being 2.14 and not significant. The F value at the 5 per cent level of significance is 2.87 for $n_1 = 4$ and $n_2 = 20$ degrees of freedom. The ranking of the varieties is the same for both dry and green yields. Thus the indication in this test is that dry yields gave a slightly more efficient test than green yields; however, the F value for dry yield analysis is so close to the 5 per cent level of significance that for most practical purposes it would not be taken too literally. Test 2A is the 1941 data of the same set of plots as for Test 2. The green yield F value is very close to being significant at the 5 per cent level and that for dry yields is significant. The ranking of the varieties is unchanged. It would thus appear that the reasonably small increase in efficiency in these two tests does not seem to justify the additional time and expense involved in the taking of moisture samples.

In Test 4 there are four strains of *Medicago media* and one strain of *Medicago falcata.* The F values for green and dry weight analyses are both significant and very similar. As in Test 3 the F value for green weights is slightly higher than the F value for dry weights. The order of varieties is unchanged. Thus the data indicate that for these two tests moisture sampling tended to increase the error variance rather than reduce it. When considering significant differences between the strains in test number 4 it is seen that the differences in average yield between strain A and strains C, D, and E are significant for both dry and green yields. Also the difference between strains B and E for green yields is significant but for dry yields it is non-significant. Since the 5 per cent level of significances is an arbitrary value such differences between significance and non-significance, as shown between strains B and E, would hardly be taken as conclusive.

Test 5A is another case where the F value for dry weights was significant at the 5 per cent level while the F value for green weights was not

TABLE 1.—SUMMARY OF THE DRY AND GREEN YIELD DATA, WITH F VALUES AND SIGNIFICANT DIFFERENCES, FOR THE COMPARATIVE TESTS CONDUCTED DURING THE PERIOD 1940-1941

Test No.	Material tested	Year	Yield data basis	Average yield of strains in pounds per plot												No. of reps.	F value for strains	L.D.S. between strains†
				A	B	C	D	E	F	G	H	I	J	K	L			
1	Alfalfa	1940	Dry	6.64	4.50	4.28	4.25	4.09	3.66							4	2.47	—
			Green	18.44	12.50	12.13	11.69	11.81	9.69							4	2.33	—
1A	Alfalfa	1941	Dry	3.63	2.80	2.36	2.32	2.13	2.04							4	2.06	—
			Green	9.26	6.76	6.01	5.63	5.13	5.13							4	1.88	—
2	Alfalfa	1940	Dry	1.64	1.60	1.29	1.25	1.19								6	2.94*	0.35
			Green	4.03	4.01	3.32	3.09	2.98								6	2.14	—
2A	Alfalfa	1941	Dry	1.66	1.48	1.23	1.19	1.08								6	3.38*	0.38
			Green	3.71	3.39	2.78	2.51	2.27								6	2.69	—
3	Alfalfa	1941	Dry	2.28	2.27	2.09	1.97	1.85	1.82							4	0.87	—
			Green	4.75	4.90	4.36	4.06	3.85	3.54							4	1.34	—
4	Alfalfa	1941	Dry	3.15	2.58	2.15	2.13	1.94								6	4.04*	0.71
			Green	8.10	6.94	6.18	5.32	5.07								6	4.22*	1.78
5	Brome grass	1940	Dry	2.17	1.95	1.88	1.84									6	0.23	—
			Green	6.66	4.31	4.10	3.92									6	0.15	—
5A	Brome grass	1941	Dry	2.78	2.33	2.33	1.82									6	3.33*	0.64
			Green	4.66	3.98	4.23	3.05									6	3.26	—
6	Crested wheat grass	1940	Dry	7.53	6.40	6.22	5.66	5.52	5.33							4	0.70	—
			Green	14.81	12.19	12.44	10.94	10.81	10.25							4	0.83	—
6A	Crested wheat grass	1941	Dry	4.97	4.53	4.47	4.47	4.05	3.64							4	0.59	—
			Green	8.47	7.30	7.61	8.28	6.89	6.64							4	0.51	—
7	Crested wheat grass	1940	Dry	10.02	8.76	7.60	7.60	7.34	7.08							4	1.21	—
			Green	16.94	13.59	12.63	13.25	12.19	11.94							4	1.39	—
7A	Crested wheat grass	1941	Dry	4.48	4.01	3.49	3.35	3.30	3.02							4	0.92	—
			Green	7.72	6.16	5.54	5.13	5.50	4.69							4	1.24	—
8	Crested wheat grass	1941	Dry	2.46	2.24	2.20	2.06	2.03	1.22							6	2.05	—
			Green	4.60	4.02	3.93	3.77	3.59	2.33							6	1.81	—
9	Standard grasses	1940	Dry	5.80	5.67	5.10	4.73	4.11	4.09							4	1.67	—
			Green	11.50	11.38	10.69	9.44	10.06	9.06							4	1.00	—
10	Standard grasses	1940	Dry	3.34	2.58	2.46	2.40	1.59								6	3.21*	0.91
			Green	6.39	5.74	4.77	4.90	3.50								6	4.23*	1.56
10A	Standard grasses	1941	Dry	4.20	3.37	2.54	2.48	2.40								6	10.26**	0.97**
			Green	6.83	5.35	4.27	4.23	5.69								6	5.80**	1.81**
11	Sweet clover	1940	Dry	5.86	5.76	5.23	4.16	4.11	3.99	3.98	3.96					6	4.38**	1.60**
			Green	19.00	19.67	18.93	13.75	13.67	15.10	13.76	12.89					6	3.62**	5.77**
12	Sweet clover	1941	Dry	4.23	4.19	3.53	3.50	3.47	3.34	3.20	3.00	2.93				6	4.74**	0.61*
			Green	13.34	12.38	12.46	10.41	11.60	10.86	10.75	10.38	10.05				6	2.17*	2.22*
13	Sweet clover	1941	Dry	3.16	3.07	3.04	2.67	2.61	2.50	1.97	1.79	1.69	1.45	1.16	1.04	6	15.09**	0.74**
			Green	9.56	10.53	9.12	9.52	9.39	7.36	6.93	5.96	5.33	5.24	3.99	3.38	6	13.78**	2.47**

* Significant at the 5 per cent level. ** Significant at the 1 per cent level. † L.S.D. – Least significant difference.

quite significant. Again no clear distinction should be drawn between the two sets of analyses as the difference is extremely small. The order of strains changed very slightly but it was far from being a significant change.

All of the tests discussed up to this point could be classed as one-crop tests because only one crop has been included in each. Even though some of these tests included more than one species it is apparently quite evident that the differences in dry matter content between the species must be relatively small. It is also evident that the green weight analyses of these tests have been as good as the dry weight analyses; at least from a practical viewpoint the detailed work of moisture sampling has not been justified.

Test number 9 is a comparative test consisting of four strains of crested wheat grass, one strain of brome grass, and one strain of slender wheat grass. As can be seen in Table 1 the F values for strains for dry and green weights are again similar and non-significant. There is one change in the order of strains but this cannot be considered as significant.

Test number 10 consisted of *Elymus junceus*, *Bromus inermis* (Common), *Agropyron cristatum* (Fairway), *Agropyron trachycaulum* and *Agropyron desertorum*, five distinctly different grasses. The F values for green and dry weight analyses are both significant to the 5 per cent level and differ by 1.02, with that for green weights being the higher one. The ranking of strains changes from A, B, C, D, E for dry weights to A, B, D, C, E for green weights. On the dry weight basis the differences between strain A and strains D and E are significant; also the difference between B and E is significant. On the basis of the green weight analysis the difference between strain A and strains C and E is significant; and also the difference between B and E is significant. Strains C and D are not significantly different in either analysis. This, therefore, is a case where the use of green weights appears to have altered the significant relationship between certain of the strains.

The 1941 data of the same set of plots, Test 10A, shows even greater differences between green and dry weight analyses. In a comparison of the F values for strains it is seen that although they both surpass the 1 per cent level of significance the F value of the dry weight analysis is almost double what it is for the green weight analysis. This would indicate that by the use of moisture data the experimental error has been reduced and the actual differences between strains have become more pronounced, thus increasing the efficiency of the test. It is also seen that the ranking of the strains on the dry weight basis, A, B, C, D, E, differs considerably from the ranking on the green weight basis, A, E, B, C, D. Strain E has been changed from the lowest yielding strain to the second highest. With changes as great as these it is quite evident that for this particular test green weights for comparative purposes would not be reliable.

The sweet clover tests, numbers 11, 12, and 13, included several strains of *Melilotus alba*, *M. officinalis*, and *M. suaveolens*. These species differ in type of plant, time of flowering, percentage of leaf, and several other characters. In Table 1 it is seen that the F values for dry and green weight analyses differ quite considerably. The ranking of strains as determined by dry and green weights in each test differ rather markedly,

with many significant changes occurring in the relationships of the strains. For example, in Test 11 varieties A and B are both highly significantly different to varieties D, E, F, G, and H on the basis of dry weights. When using green weight data variety B differs significantly from varieties D, E, G and H but A is only significantly different to H.

Again it is obvious that green weights, as a basis for comparison of treatments in these tests, would be unreliable.

It thus becomes apparent that the data in Table 1 could be classified into two distinct groups, one-crop tests, as previously mentioned, and secondly, several crop tests. Some further evidence for this grouping is obtained from an examination of the dry matter percentage data from these tests, which appear in Table 2. In Table 2 the order of the strains for each test corresponds to the order of strains given in Table 1.

Of the thirteen one-crop tests, numbers 1 to 8, inclusive, there are only six cases in which the F value for strains is significant, and of these, three are significant at the 1 per cent point. In these tests, 4, 5A, and 7A, although the strains are highly significantly different the actual maximum differences in dry matter percentage are relatively small, less than 15 per cent of the lower range. It has already been pointed out that in these tests the green weight analysis gave essentially the same results as the dry weight analysis. In seven of the thirteen tests replicates are shown to be significantly different, and of these, three are significant at the 1 per cent point. Significant differences between replicates in the dry matter percentage appear to have very little effect on yield data. An example of how little these differences affect the yield data is given by Test number 1A where strain differences are not significant and replicates are highly significantly different. On referring back to Table 1 it is seen that the variance analysis of the green yields gave essentially the same results as the variance analysis of the yields after the dry matter percentages had been taken into consideration.

The six tests, numbers 9 to 13, inclusive, show somewhat different results. In every case strains are highly significantly different for dry matter percentage, with maximum differences between the strain averages generally being greater than for tests 1 to 8, inclusive. It is therefore to be expected that for this group of tests green weight analysis would give very different results from dry weight analysis.

Since the one-crop tests have such small differences in dry matter percentage between the strains, and since the green weight analysis appears to be as satisfactory as dry weight analysis, for comparative purposes, detailed moisture sampling would be unnecessary. However, the general practice of reporting forage yields is to report, at 12 to 15 per cent moisture, the pounds or tons of hay produced per acre. The most practical method of reducing green yields to dry yields and then back to the desired percentage moisture would be to take five or six moisture samples at random over the entire test, determine the average percentage dry matter, and use this average to change green weights to hay weights. The comparison of the hay yields on this basis would be exactly the same as the comparison on the basis of the green yields. By using this method the data become

TABLE 2.—SUMMARY OF THE DRY MATTER PERCENTAGE DATA, WITH F VALUES AND SIGNIFICANT DIFFERENCES, FOR THE COMPARATIVE TESTS CONDUCTED DURING THE PERIOD 1940-1941

Test No	Material tested	Year	Treatment	Average per cent dry matter												F values	L S D†
				A	B	C	D	E	F	G	H	I	J	K	L		
1	Alfalfa	1940	Strains	36.0	35.8	35.4	36.5	35.5	37.9							1.21	—
			Reps	36.7	36.5	36.3	35.2									0.85	—
1A	Alfalfa	1941	Strains	39.0	41.0	41.1	41.0	42.6	41.5							0.56	—
			Reps	43.4	42.3	41.8	36.6									5.49**	5.35
2	Alfalfa	1940	Strains	41.2	40.4	38.7	41.3	40.5								1.16	—
			Reps	41.8	41.5	41.4	41.3	39.2	37.2							2.94**	3.2
2A	Alfalfa	1941	Strains	46.3	44.4	45.0	47.6	47.9								0.99	—
			Reps	51.5	46.4	46.4	45.7	44.1	43.4							2.86*	5.0
3	Alfalfa	1941	Strains	48.0	46.9	48.2	48.6	48.3	51.4							1.24	—
			Reps	50.6	49.0	48.5	46.1									2.91	—
4	Alfalfa	1941	Strains	38.5	37.2	34.9	40.2	38.3								6.32**	3.1
			Reps	39.9	39.5	36.8	36.8	37.4	36.4							3.19*	2.5
5	Brome grass	1940	Strains	48.9	45.3	46.0	46.9									3.58*	2.5
			Reps	47.9	47.3	46.9	46.5	46.1	45.9							0.55	—
5A	Brome grass	1941	Strains	60.0	59.2	55.1	60.2									14.31**	2.6
			Reps	62.4	60.5	58.2	57.6	57.2	55.9							9.47**	3.2
6	Crested wheat grass	1940	Strains	50.9	52.1	50.1	51.5	50.5	51.4							0.96	—
			Reps	52.1	52.0	51.4	49.0									5.70**	2.5
6A	Crested wheat grass	1941	Strains	59.6	62.0	59.0	53.4	58.8	54.7							3.76*	5.0
			Reps	59.2	58.3	57.1	57.0									0.62	—
7	Crested wheat grass	1940	Strains	59.0	63.1	59.4	57.0	59.4	58.9							3.51*	3.2
			Reps	61.9	59.8	58.4	57.7									4.67*	3.7
7A	Crested wheat grass	1941	Strains	58.2	65.5	64.1	65.7	60.2	65.4							11.90**	3.9
			Reps	64.5	63.9	62.9	61.5									3.04	—
8	Crested wheat grass	1941	Strains	53.7	56.2	56.8	54.8	56.0	52.1							1.50	—
			Reps	56.7	56.5	55.5	54.4	53.7	52.9							1.12	—
9	Standard grasses	1940	Strains	49.8	49.5	47.8	48.4	40.7	44.5							4.72**	6.8
			Reps	49.3	48.3	45.9	43.7									3.58*	4.0
10	Standard grasses	1940	Strains	52.2	45.1	51.6	48.8	45.2								41.26**	2.1
			Reps	49.7	49.3	48.6	48.1	47.9	47.6							2.04	—
10A	Standard grasses	1941	Strains	61.6	63.3	60.0	60.2	41.2								147.87**	3.0
			Reps	58.5	57.6	57.3	56.8	56.6	56.5							0.88	—
11	Sweet clover	1940	Strains	30.8	29.6	29.1	30.3	30.3	29.1	26.2	31.1					11.32**	1.8
			Reps	30.6	30.3	30.1	29.6	28.4	28.2							6.50**	1.5
12	Sweet clover	1941	Strains	31.7	34.3	28.6	33.7	30.0	30.8	30.1	29.2	29.3				7.74**	2.8
			Reps	32.6	31.3	30.6	30.6	30.4	30.0							2.00	—
13	Sweet clover	1941	Strains	33.2	29.3	33.4	28.0	28.1	34.1	28.5	30.0	32.7	28.0	28.7	28.7	14.16**	2.4
			Blocks	30.8	30.5	30.4	30.3	30.2	29.1							1.67	—
			Columns	31.0	30.7	30.5	30.4	29.5	29.1							2.78*	1.3

* Significant at the 5 per cent level ** Significant at the 1 per cent level. † Least significant difference.